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Selected physical and water properties of alluvial soils in the context of their susceptibility to drainage degradation

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Abstract

In terms of the mutual arrangement of individual properties, alluvial soils are unpredictable and do not fit into the regularities most often found in arable soils. Often, soil density does not increase with the sampling depth, and the carbon content in endopedons is irregularly distributed, in line with the quality of alluvial deposits. These soils may react differently to the lowering of the groundwater table, especially in the case of fine textured and very fine textured alluvial soils. The paper presents selected physical and water properties of fine textured alluvial soils in the middle proglacial stream valley of the Warta River (central Poland, near Koło). Seven soil profiles were made. During field studies, taxonomic and soil suitability classifications of the analyzed soils were carried out. These were: humic proper alluvial soils, typical humic alluvial soils, and rusty humic alluvial soils. The investigated soils were occupied by grasslands of the 4th and 5th valuation class. The following properties were determined: texture, organic matter content, content of total carbon and total nitrogen, particle density, bulk density, total and drainage porosity, saturated hydraulic conductivity, moisture at particular soil water potentials, total and readily available water, soil reaction in H_2O and in KCl. Most of them were strongly influenced by the alluvial genesis of the studied soils, and more specifically - the type and nature of the river deposits that formed the individual genetic horizons, yet they can be considered as characteristic of cultivated soils with a similar texture, occurring in the Central Polish Lowlands. The susceptibility of these soils to drainage degradation was determined due to their location in the marginal zone of the depression cone of the lignite mine "Drzewce". It was found that the top horizons of these soils has undergone the decession process due to their natural and meliorative drainage in the past. Therefore, such soils cannot be subject to drainage mine productivity degradation.

1. Introduction

Alluvial soils are interesting for many reasons. In their genesis, the geological process dominates soil-forming processes or – at least – significantly modifies their character (Strzemski, 1955; Laskowski and Szozda, 1985; Falkowski, 2015). For this reason, in different classifications, these soils function as a separate order/type or are assigned to different taxonomic units (SgP, 2011; Kabała, 2014; Kabała et al., 2016, 2019). In terms of the mutual arrangement of individual properties, alluvial soils are unpredictable and do not fit into the regularities most often found in arable soils. Often, soil density does not increase with the sampling depth, and the carbon content in endopedons is irregularly distributed, in line with the quality of alluvial deposits. These soils may react differently to the lowering of the groundwater table, especially in the case of fine textured and very fine textured alluvial soils (Rząsa et al., 1999). In the literature, studies of the properties of fine textured alluvial soils are widely represented. Few of the available data concern alluvial soils formed of sandy material or those with dominance of sand. The paper presents selected physical and water properties of such soils, and an attempt was made to assess their susceptibility to potential drainage, caused by the impact of the trench of the lignite mine open-pit adjacent to the studied separation.

2. Materials and methods

The research was conducted in October 2018 as part of the soil science expertise, aimed at determining the degree of mine drainage degradation caused by the cubature trench of the Drzewce open pit Konin Lignite Mine (Owczarzak et al., 2018). The research object was located in the marginal zone of the theoretical tertiary depression cone, with a range of 3850 m, and within the depression cone corrected by measurements of the depth of groundwater deposition (about 5800 m). The research points were located on the land of four villages: Borki, Barce, Ochle and Lubiny (Wielkopolskie Voivodeship, Koło district, Koło commune), which are located in a strip of land along the Warcica River, with the villages of Ochle and Lubiny adjacent to the Warta River in the south (Figure 1). During field studies, taxonomic and soil suitability classifications of the analyzed soils were carried out. Morphological structure and taxonomic classification were described in accordance with the Polish Soil Classification (SgP, 2019). Seven soil profiles were made. These were: humic proper alluvial soils (1, 4, 6, 7). Typical humic alluvial soils (2, 3), and rusty humic alluvial soils (5). The investigated soils were occupied by grasslands of the 4th and 5th valuation class. During 2018, twelve monthly. measurements of the groundwater level were conducted. The usefulness of such measurements was confirmed in previous studies (Owczarzak et al., 2008, 2017). These parameters provide key information that is used to infer the impact of the excavation operation on the surrounding areas. Such tests should be carried out in stages: before the launch of the drainage barrier, during the exploitation of the deposit, as well as after backfilling of the pit, so that it is possible to reliably assess the impact of the pit on the properties of adjacent soils and their potential productivity (Gajewski and Kaczmarek, 2021).

Disturbed and intact samples (V = 100 cm^3) were collected from the individual genetic soil horizons. The collected material was used to analyse the following soil properties: texture of the mineral horizons, using Cassagrande method in the modification by Prószyński (Mocek and Drzymała, 2010); particle density in the mineral horizons using the pycnometer method (Blake and Hartge,1986); bulk density using metal cylinders of known (100 cm^3 volume); total porosity was calculated on the basis of the determinations of particle density and bulk density (Mocek and Drzymała, 2010); drainage porosity was determined as the difference between total porosity and the moisture content that corresponds to field capacity (indicated at –10 kPa matric potential), which is a corresponding value at pF = 2.0; organic matter content (OMC), by placing samples in a muffle furnace at 550°C (Grimshaw et al., 1989); total carbon content (Ctot) and total nitrogen content (Ntot) using a VarioMax CNS analyser, reaction of the soil with the soil: solution ratio of 1:2.5 using H_2O and 1M KCl as a suspension medium, maximum hygroscopicity (MH – moisture content at pF 4.5) was determined in a vacuum chamber at 0.8 atm. with a potassium sulphate (K_2SO_4) saturated solution (Mocek and Drzymała, 2010); soil water potential using the Richards pressure chamber method (Klute, 1986); total available water (TAW) and readily available water (RAW) were calculated on the basis of pF determinations (Mocek and Drzymała, 2010) and saturated hydraulic conductivity (Ks) was determined by the constant pressure head method (Klute and Dirksen, 1986). All results presented here are the mean value of three replications and Pearson correlation coefficient was calculated

3. Results and discussion

The texture of almost all the examined soils (1–6) showed a composition of sands with a clay fraction content of 1 to 5% and of silt fraction from 3 to 19%, occasionally layered with poorly compacted clay silt (PTG, 2009). A different, loamy texture was found in profile 7. Although it is difficult to imagine loam of alluvial origin, the averaged results of the samples taken from

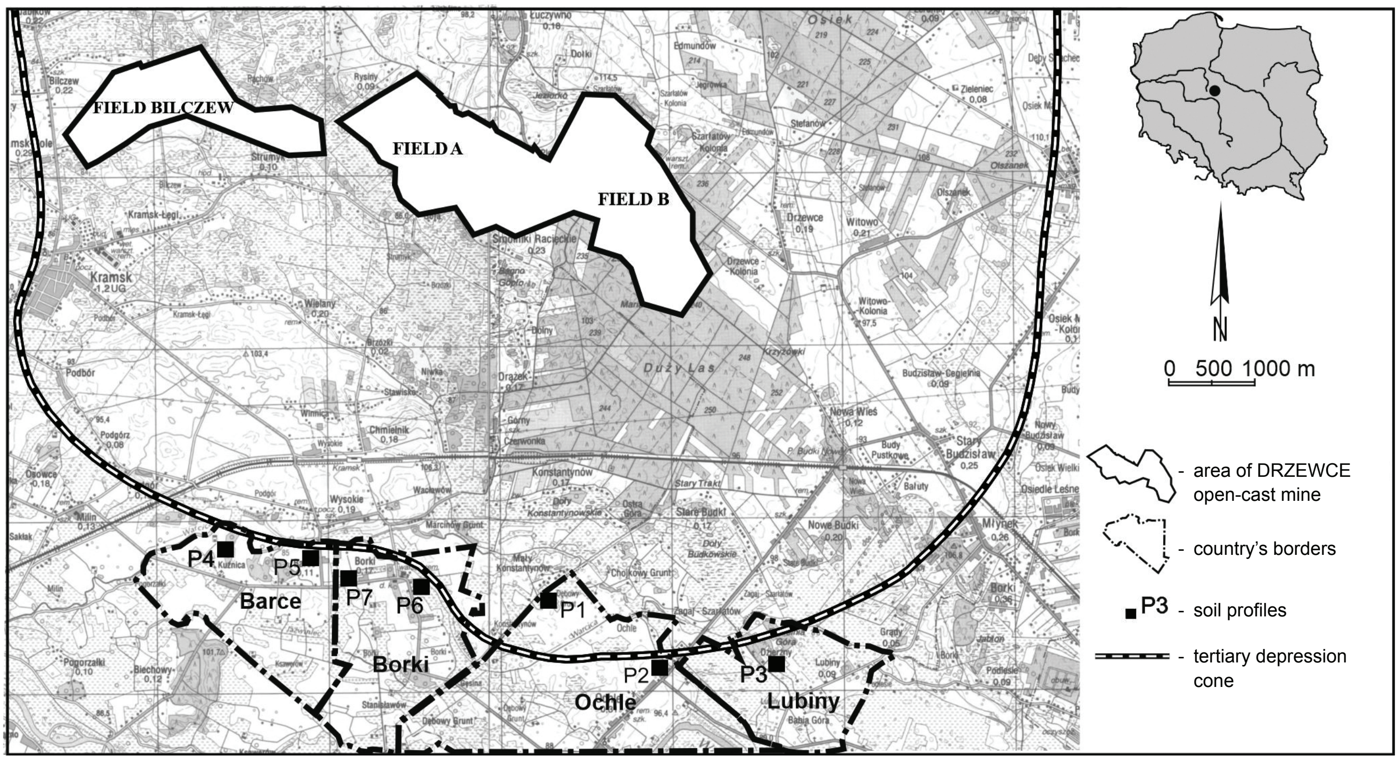

Fig. 1. Location of examined soils.

individual horizons showed that they belonged to the texture subgroups of sandy loam and loam, and a clear layering and lining of these deposits with alluvial sand undoubtedly qualified this soil as alluvial soil (Table 1).

The particle density ranged from 2.51 to 2.65 Mg m^{-3} (Table 2). These values were strongly correlated with the organic matter content (r = –0.97). Bulk density and, closely related to it, total porosity, were stable only in soil 7, with loam texture – within the following ranges: 1.42–1.54 Mg m^{-3} and 41.2–45.3% v/v. In the case of sandy soils (1,6) these properties were highly diversified: bulk density from 1.08 to 1.63 Mg m^{-3}; total porosity from 38.3 to 58.8% v/v. In individual profiles, epipedons were characterized by the lowest density and high porosity, but the arrangement of these properties in endopedons was definitely irregular, usually independent of the depth of sampling. The local layers of sandy material with silt were low compacted (Table 2). In terms of physical properties Łyczko et al. (2007), obtained slightly (up to about 4%v) lower values of the total porosity – with a higher particle density. The saturated hydraulic conductivity in the sands was high, in the following ranges: sands-coarser – 29.4–73.6; sands-finer – 17.3–24.5; loamy sands – 7.3–16.2 µm s^{-1}. It had much lower values in silts: 1.1–2.1 and loams: 0.7–1.2 µm s^{-1} (Table 3). The calculated drainage porosity correlated with the saturated hydraulic conductivity at the level of r = 0.58. Based on the above data, it can be concluded that in the studied soils there is an intensive natural drainage of rainwater and those from the winter reserve, with the possibility of their short-term stagnation over loams and silts. The determined saturated hydraulic conductivity was characteristic of individual texture formations, slightly higher than the values given by Kolis (Zawadzki, 2002), consistent with the Ks values obtained by Zawadzki and Olszta (Zawadzki, 2002) and within the broad ranges cited by many authors (Krogulec, 1994).

In the examined soils, the maximum water capacity was close to the total porosity. They were usually 2–3% lower. All other water capacities were characterized by significant variability within individual profiles, which can be considered a typical feature of alluvial soils. Their values depended mainly on the

Table 1
Texture of examined soils

Soil profile	Soil horizon	Depth (cm)	Content (%) of particle-size fraction (mm)						Texture acc. to PTG 2008
			2–0.1	0.1––0.05	0.05––0.02	0.02––0.005	0.005––0.002	<0.002	
1	Ah	0–25	67	11	13	4	2	3	LS
	C1	25–37	71	12	8	6	2	1	LS
	C2	37–62	23	13	25	16	10	13	CS
	C3	62–120	22	12	27	17	8	14	CS
2	A	0–40	77	12	3	3	2	3	SF
	C1	40–67	88	4	4	2	1	1	SC
	C2	67–90	17	13	34	16	5	15	CS
3	A	0–20	81	8	6	3	1	1	SF
	C1	20–30	90	2	5	1	0	2	SC
	C2	30–40	20	11	25	18	11	15	CS
	C3	40–80	87	8	1	1	2	1	SC
4	Ah	0–28	67	11	10	5	3	4	LS
	C1	28–90	94	2	2	1	0	1	SC
5	A	0–30	82	6	4	3	3	2	SF
	ABv	30–55	86	7	3	2	1	1	SC
	C	55–78	93	3	2	1	0	1	SC
	2C	78–100	64	17	8	3	3	5	LS
6	Ah	0–23	67	16	8	4	3	2	LS
	C1	23–38	95	1	3	0	0	1	SC
	C2	38–100	96	1	2	0	0	1	SC
7	Ah	0–23	44	15	19	9	6	7	SLC
	C1	23–50	21	17	28	14	8	12	L
	C2	50–75	40	27	15	6	4	8	SLC
	C3	75–100	88	7	3	1	0	1	SC

Explanation: LS – loamy sand; CS – clay silt; SF – sand-finer; SC – sand-coarser; SLC – sandy loam coarser; L – loam

Table 2
Selected physical properties of examined soils

Soil profile	Soil horizon	Depth (cm)	Particle density (Mg m^{-3})	Bulk density (Mg m^{-3})	Total porosity (%v)
1	Ah	0–25	2.59	1.59	38.6
	C1	25–37	2.63	1.61	38.8
	C2	37–62	2.59	1.15	55.6
	C3	62–120	2.62	1.08	58.8
2	A	0–40	2.59	1.16	55.2
	C1	40–67	2.64	1.48	43.9
	C2	67–90	2.63	1.23	53.2
3	A	0–20	2.50	1.12	55.2
	C1	20–30	2.62	1.50	42.7
	C2	30–40	2.61	1.52	41.8
	C3	40–80	2.63	1.45	44.9
4	Ah	0–28	2.60	1.56	40.0
	C1	28–100	2.64	1.63	38.3
5	A	0–30	2.61	1.28	51.0
	Abv	30–55	2.63	1.49	43.3
	C	55–78	2.65	1.61	39.2
	2C	78–100	2.51	1.62	35.5
6	Ah	0–23	2.57	1.37	46.7
	C1	23–38	2.64	1.57	40.5
	C2	38–100	2.65	1.60	39.6
7	Ah	0–23	2.52	1.42	43.7
	C1	23–50	2.62	1.54	41.2
	C2	50–75	2.64	1.52	42.4
	C3	75–100	2.65	1.45	45.3

Table 3
Selected water properties of examined soil

Soil profile	Soil horizon	Depth (cm)	Water capacity (%) at pF:					TAW	RAW	Drainage porosity (%v)	Saturated hydraulic conductivity (μm s^{-1})
								(%v)			
			0	2.0	3.7	4.2	4.5	2.0–4.2	2.0–3.7		
1	Ah	0–25	35.7	21.9	11.6	9.4	2.5	12.5	10.3	16.7	9.8
	C1	25–37	35.1	19.4	9.9	6.2	2.0	13.2	9.5	19.4	7.3
	C2	37–62	52	28.6	16.8	12.8	5.9	15.8	11.8	27.0	1.6
	C3	62–120	54.2	26.7	14.7	11.3	6.2	15.4	12.0	32.1	1.3
2	A	0–40	52.4	15.5	8.8	6.0	1.6	9.5	6.7	39.7	17.3
	C1	40–67	40.6	7.3	5.5	3.3	1.2	4.0	1.8	36.6	29.4
	C2	67–90	49.5	24.2	15.3	10.4	4.7	13.8	8.9	29.0	2.1
3	A	0–20	53.5	18.4	10.1	4.5	2.3	13.9	8.3	36.8	17.5
	C1	20–30	39.5	8.3	5.7	2.3	0.9	6.0	2.6	34.4	51.3
	C2	30–40	39.2	24.2	15.8	10.9	4.8	13.3	8.4	17.6	1.1
	C3	40–80	41.4	11.4	8.4	3.2	1.1	8.2	3.0	33.5	46.7
4	Ah	0–28	38.2	19.0	10.3	8.0	2.2	11.0	8.7	21.0	16.2
	C1	28–100	36.4	9.4	6.8	4.2	1.8	5.2	2.6	28.9	45.1
5	A	0–30	47.3	13.5	7.8	4.0	1.8	9.5	5.7	37.5	24.5
	Abv	30–55	41.0	8.2	5.5	3.6	0.8	4.6	2.7	35.1	51.1
	C	55–78	37.9	6.4	5.2	3.2	0.9	3.2	1.2	32.8	73.6
	2C	78–100	33.5	22.9	14.2	8.5	2.4	14.4	8.7	12.6	8.4
6	Ah	0–23	42.1	15.2	10.1	4.7	2.3	10.5	5.1	31.5	11.2
	C1	23–38	38.7	9.6	5.4	2.7	1.1	6.9	4.2	30.9	36.6
	C2	38–100	37.2	7.3	5.2	3.3	2.8	4.0	2.1	32.3	42.8
7	Ah	0–23	41.3	24.7	17.5	8.5	4.7	16.2	7.2	19.0	0.8
	C1	23–50	40.1	28.2	11.4	9.5	6.3	18.7	16.8	13.0	0.7
	C2	50–75	41.1	25.2	16.3	10.4	4.8	14.8	8.9	17.2	1.2
	C3	75–100	43.1	9.8	6.5	3.5	1.2	6.3	3.3	35.5	64.1

Explanation: RAW – readily available water; TAW – total available water

content of clay fraction (r from 0.80 at pF 3.7 to 0.87 at pF 4.2) and – to a much lesser extent – on the content of organic matter (r from 0.28 at pF 4.2 to 0.45 at pF 3.7). The field water capacity (FWC, pF = 2.0) of the loamy sands was about 15–23%; sands-finer about 13–18%; sands-coarser about 6–11%. The highest FWC values were obtained in formations finer than sands; in clay silt about 24–29%, in loams about 25–28%. Field water capacity correlated with the content of clay fraction at the level of r = 0.81. At the refill point (pF 3.7), the water content – relative to FWC – decreased most strongly in loams – by about 7–17%. For clay silts, the decrease in water content at refill point was lower – by about 8–12%; in loamy sands the values were lower than the field water capacity by about 5–10%, in sands-finer by 6–8%; in sands-coarser by 1–4%. The decrease in water content between pF 3.7 and pF 4.2 was much smaller, locating the lower limit of water availability within the following limits: 2.3–9.4% in sands; 10.9–12.8% in silts; 8.5–10.4% in loams. The maximum hygroscopicity (pF 4.5) values were characteristic of the deposits representing individual texture subgroups (Rząsa et al., 1999), ranging from 0.8 to 2.8 for sands; from 4.7 to 6.2 for silts and from 4.7 to 6.3% for loams. This property was strongly correlated with the content of clay fraction (r = 0.90). (Table 3).

The calculated values of TAW and RAW depended mainly on the colloid content (TAW: r = 0.71; RAW: r = 0.70). Their values were as follows: in total available water (TAW) loamy sands from 10.5 to 14.4%, with readily available water (RAW) ranging from 5.1–10.3%; in the sands-finer lower values were found: TAW from 9.5 to 13.9, RAW 6.7–8.3%. Sands-coarser had the lowest retention rates: TAW 3.2–8.2, RAW 1.2–4.2%. TAW and RAW in clay silts had the values within 13.3–15.8% and within 8.4–12%. The highest retention rates were observed in loams: TAW – 14.8–18.7, RAW 7.2–16.8% (Table 3). Łyczko et al. (2007) give the amount of water reserve in alluvial soils with texture similar to that of the tested soils, based on five-year, monthly determinations of the current moisture content. After averaging and recalculation of these data and estimation of TAW on their basis, it was found that they are very similar (differences up to about 2% v) to those presented in the paper. In the research by Brandyk (1988), selected genetic profiles and horizons showed similar total porosity in the case of loams and lower – in the sands. The water content at pF = 2.0 determined by this author was much higher both in the case of loams and sands, and for the coarser sands they were very differentiated (5.1–24.5% v).

The basic chemical properties of examined soils show a favorable picture from an agricultural point of view. The pH of epipedons measured in H_2O was balanced and ranged from 5.65 to 6.36. In endopedones the pH was more differentiated, pH – from 5.05 to 7.32. In 1M KCl, the pH was usually about 0.5–1 unit lower (Table 4). These values were low, but often found on sandy soils, used – to a large extent – as extensive meadows and pastures (Rząsa et al., 1999.).

Organic matter content in epipoedons ranged from 2.65 to 12.1%, with total carbon content – respectively: 1.3–6.1%, and in endopoedons from 0.52 to 11.2 with total carbon within range: 0.21–5.6%. The content of total nitrogen in epipedones ranged from 0.10 to 0.50%; in endopedones it varied within wide limits: from 0.02 to 0.41%. The C:N ratio was favorable, close to optimal values. In epipedons it was 9.6–13.5 (Table 4). A strong relationship was observed between the content of organic matter and the content of total nitrogen: r = 0.97. Czyż et al. (2013) observed – in fine and very fine textured alluvial soils – very similar pH values (4.22–6.08) and the C:N ratio (7.8–10.8). In the case of alluvial soils, comparing the content and distribution of organic matter in soils representing different objects seems unjustified, because its randomness and irregularity result from the variability and specificity of the sediments carried by the river in the past, the frequency and duration of flooding, and locally dominant soil-forming factors.

Referring to the results obtained by other authors and commenting on possible similarities and differences is difficult and debatable in the case of alluvial soils. This is due to the quantitative and qualitative irregularity of the deposits that form them, random foundation of mineral and organic deposits at different depths, the interaction of various, variable thickening factors, etc.

4. Summary

The studied soils formed mainly of sandy materials, which were characterized by the type of precipitation-water regime. Their stabilized groundwater table was beyond the reach of the

Table 4
Selected chemical properties of examined soils

Soil profile	Soil horizon	Depth (cm)	pH		OMC	Ctot	Ntot	C:N
			H_2O	KCl		(%)		
1	Ah	0–25	5.86	5.34	5.27	2.6	0.21	13.0
	C1	25–37	6.06	5.47	2.46	1.7	0.11	17.0
	C2	37–62	6.19	5.61	5.41	2.7	0.2	13.5
	C3	62–120	5.51	4.54	2.76	1.4	0.15	10,0
2	A	0–40	5.81	5.38	4.36	1.3	0.11	11.8
	C1	40–67	6.75	5.82	1.9	1.13	0.1	11.3
	C2	67–90	7.01	6.03	0.71	0.24	0.02	12.0
3	A	0–20	6.36	5.3	12.1	6.1	0.5	12.2
	C1	20–30	7.18	6.2	2.4	1.2	0.1	12.0
	C2	30–40	7.32	6.38	3.07	1.5	0.13	11.5
	C3	40–80	5.05	4.2	1.62	0.8	0.07	11.4
4	Ah	0–28	5.72	5.16	5.36	2.7	0.2	13.5
	C1	28–100	6.08	5.48	2.37	1.2	0.1	12.0
5	A	0–31	5.65	5.32	2.65	1.3	0.1	13.0
	Abv	30–55	5.72	5.09	0.88	0.5	0.04	12.5
	C	55–78	5.79	5.12	0.64	0.3	0.03	10.0
	2C	78–100	5.61	4.92	11.2	5.6	0.41	14.0
6	Ah	0–23	5.7	5.21	5.09	2.5	0.26	9.6
	C1	23–38	5.41	5.01	0.86	0.45	0.04	11.3
	C2	38–100	5.62	5.07	0.52	0.21	0.02	10.5
7	Ah	0–23	5.7	5.32	9.1	4.4	0.42	11.0
	C1	23–50	5.8	5.01	3.4	2.5	0.2	12.5
	C2	50–75	5.7	5.1	2.27	1.3	0.1	13.0
	C3	75–100	5.9	5.5	1.51	0.6	0.05	12.0

Explanation: OMC – organic matter content, Ctot – total carbon content, Ntot – total nitrogen content soil profile. The production water in them came exclusively from precipitation, which periodically saturated the porosity, maximally up to the field water capacity. Quickly percolating gravity water does not have the possibility of periodic stagnation on poorly permeable layers, which excludes its effective redistribution by capillary rise (except for the soils represented by profiles 1 and 7, showing an alternate regime). Therefore, such soils cannot be subject to drainage mine productivity degradation. Based on many years of research (expert opinion), it was found that due to their natural and meliorative drainage in the past, the top horizons of these soils, or more precisely, the organic matter contained in them, has undergone the decession process and is maintained at a stable level, maintaining a favorable carbon to nitrogen ratio.

It is true that the marked physical and water properties can be regarded as typical, characteristic of arable soils, with a different genesis but similar texture occurring in the Central Polish Lowlands. However, most of them were strongly influenced by the alluvial genesis of the soils, and more specifically the type and nature of the river deposits that constituted the individual genetic horizons. The resulting irregularity in the values of individual properties at different depths, clearly distinguishes the studied soils from other mineral soils, and the strong influence – often dominance – of the geological process over the soil formation process suggests the possibility of treating them as an autonomous systematic unit.

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Wybrane właściwości fizyczne i wodne mad w kontekście ich podatności na degradację odwodnieniową

Słowa kluczowe

Gleby aluwialne
Degradacja odwodnieniowa
Właściwości fizyczne i wodne
Zapas wody

Streszczenie

Pod względem wzajemnego układu poszczególnych właściwości, mady są glebami nieprzewidywalnymi i nie wpisują się w najczęściej stwierdzane w glebach uprawnych prawidłowości. Często gęstość gleby nie wzrasta w nich wraz ze wzrostem głębokości pobrania próbki, a zawartość węgla w endopedonach rozkłada się nieregularnie, zgodnie z jakością nanosów aluwialnych. Gleby te mogą w różny sposób reagować na obniżanie się zwierciadła wód gruntowych, a szczególnie dotyczy to mad lekkich i bardzo lekkich. W pracy przedstawiono wybrane właściwości fizyczne i wodne mad lekkich pradoliny środkowej Warty (środkowa Polska, okolice Koła). Wykonano siedem profili glebowych. Opisano budowę morfologiczną gleb oraz ich klasyfikację systematyczną i użytkową. Były to: mady właściwe próchniczne, mady czarnoziemne oraz mady czarnoziemne rdzawe. Badane gleby zajęte były przez użytki zielone IV i V klasy bonitacyjnej. Oznaczono: uziarnienie, zawartość materii organicznej, węgla i azotu ogólnego, odczyn, gęstość gleby oraz fazy stałej, porowatość całkowitą i drenażową, współczynnik filtracji, wilgotność przy poszczególnych potencjałach wiązania wody przez glebę, potencjalną i efektywną retencję użyteczną oraz odczyn w H_2O i w 1M KCl. Na większość z oznaczonych parametrów silnie oddziaływała aluwialna geneza badanych gleb, a konkretnie rodzaj i charakter nanosów rzecznych, które budowały poszczególne poziomy genetyczne, niemniej można uznać je za charakterystyczne dla gleb uprawnych o zbliżonym uziarnieniu, występujących na Niżu Środkowopolskim. Określono podatność tych gleb na kopalnianą degradację odwodnieniową, z uwagi na ich usytuowanie w marginalnej strefie leja depresji odkrywki kopalnianej węgla brunatnego „Drzewce". Stwierdzono, że poziomy wierzchnie tych gleb uległy w przeszłości decesji wskutek ich naturalnego, uprawowego oraz melioracyjnego odwodnienia i nie mogą podlegać odwodnieniowej kopalnianej degradacji produktywności.