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PHYSICAL AND WATER PROPERTIES OF ARABLE SOILS LOCATED IN THE AREA OF A PREDICTED DEPRESSION CONE OF "TOMISŁAWICE" LIGNITE OPEN-CAST MINE (CENTRAL POLAND)

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Abstract. In this paper the authors present the characteristics of selected physical and water properties of four arable soils situated within the range of the predicted depression cone of "Tomisławice" lignite open-cast mine. In the sampled soil material of undisturbed and disturbed structure following properties were determined: texture, particle density, bulk density, total porosity, hygroscopic moistures, maximal hygroscopic capacity, saturated hydraulic conductivity, potentials of water bonding in soil, total and readily available waters, total retention in the soil layers of 0–50 and 0–100 cm, drainage porosity and content of organic matter. Studied soils were developed from sands, sandy loams and sapric peat material. All of the analyzed soil properties were determined by clay fraction or organic matter content in particular. In most of the investigated soils, high field water capacity and wide scopes of total and readily available water were recorded. Measured saturated hydraulic conductivity was typical for arable soils with similar origin. Studied soils showed a precipitation water regime and probably will not be exposed to drainage degradation caused by open-cast mine.

Keywords: soil drainage degradation, lignite mining, mineral and organic soils

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INTRODUCTION

The assessment of stage and scope of dehydrating degradation is a complex problem. The process of degradation may be caused by either intentional or unplanned dehydration. There is no doubt that a mine depression cone affects a part of soils adjacent to the exposure. Lignite open-cast mining leads to significant hydrological and geo-mechanical transformations of the lithosphere surface layers (Gajewski *et al*. 2015). Mentioned changes are visible not only within boundaries of the open-cast mines, but even in the areas adjacent to them (Glina *et al*. 2016b). However, degradation is also triggered by natural evolutionary processes in soils, often referred to as natural degradation, which strengthens as a result of intensification of arable production and inappropriate or too intensive utilization. Constant increase of global amount of water taken out from soil with growing crops, together with periodical hydrological low-waters, as well as the effects of meliorations, which are sometimes conducted inappropriately, leads to the decrease of the depth of ground water retention, permanent decrease of the content of organic matter is soils and negative changes in numerous other parameters. Nevertheless, soils which are prone to degradation changes caused by dehydrating mining, are the ones whose plants may use ground waters effectively (Rząsa *et al*. 1999). Soil research which precedes cubic excavation, should consist of at least two stages (Owczarzak *et al*. 2017). The first should be done before initiation of mining activities. It covers a detailed documentation of soil cover. The latter, conducted once the opencast is overwhelmed, should be aimed at the determination of potential negative changes of soil properties which might have occurred as a result of their dehydration degradation (Rząsa *et al*. 2000). In the meantime, within several years of impact of an active dehydration barrier, it is advised to conduct an ongoing monitoring of ground water level in the selected points (Lekan and Terelak 2000). Since damages claims in respect of degradation of arable lands' productivity often concern farms located significantly far from the open-cast mine, preliminary inventory research must cover vast areas, which generates very high (difficult to accept by an ordering party) cost of expertise (Rząsa *et al*. 1999). In such cases a procedure of preliminary soil cover identification should be applied for each vast territory and, on the basis of this documentation, parts of it should be identified as insusceptible to open-cast dehydration degradation and excluded from further, more detailed research (Mocek *et al*. 2000). The aim of the paper was to assess the current state of various type of arable soils adjacent to "Tomisławice" lignite open-cast mine, based on the selected physical and water properties determination.

MATERIALS AND METHODS

Study area

The research area is located at the border of two voivodeships: Wielkopolskie (district of Wierzbinek) and Kujawsko-Pomorskie (district of Piotrków Kujawski). It covers three villages: Szewce, Rudzk Duży and Rudzk Mały. The study area directly adjacent to the excavations of "Tomisławice" open-cast, within the range of a possible dehydration depression cone. In terms of physiography, it is a complex of numerous tunnel subsidences on a local elevation between the Warta-Gopło Canal, Lake Gopło and Noteć River Valley (Kondracki 2009). The research area covered a bottom-moraine plain of Vistulian glaciation (Krygowski 1961) with a flat and low-crinkled relief. Parent materials of the investigated soils were sands, boulder clay and sapric peat. Their natural value and arable suitability were highly differentiated: evaluation classes and complexes of arable suitability from II, KRP 2 (profile 1) to VI, KRP 7 (profile 4) (Mocek and Drzymała 2010).

Field survey and laboratory analysis

Soil diversity, the reach of allotments and soils character were marked on the basis of control drillings. Over a dozen of sampling points were determined. The paper contains properties of soils from four of them, which were the most characteristic for each large allotment. Study soils were classified with the Polish Soil Classification (PSC 2011) and FAO-WRB system (IUSS Working Group 2015). Soil samples for laboratory analysis were sampled by genetic soil horizons, both, mixed samples and undisturbed soil samples. In the sampled soil material following properties were determined: soil texture – particle-size distribution in mineral horizons using sieves for sand separation and the hydrometer method for silt and clay fractions (PKN 1998), decomposition rate of organic materials using Von Post scale (Von Post 1922), particle density of mineral horizons (with a picnometric method) (Soil Conservation Service 1992), particle density of organic horizons was calculated with Zawadzki's formula (Okruszko and Piaścik 1990), bulk density using Nitzsch's vessels of 100 cm^3 capacity, total porosity calculated based on particle and bulk density, soil moisture using a drying-weight method (Mocek and Drzymała 2010), organic matter content after placing dried samples for 5h in a muffle furnace at 550^{o}C (Bojko and Kabala 2014), hygroscopic water (H) and hygroscopic capacity (MH) (calculated in a vacuum chamber at 0.8 atm. subpressure with K_2SO_4 saturated solution) (Mocek and Drzymała 2010), saturated hydraulic conductivity (with the method of constant pressure decrease) (Klute and Dirksen 1986), soil's water bond potentials (with the method of Richards' pressure chambers) (Klute 1986), total available water (TAW) and readily available water (RAW) calculated based on pF values, effective (drainage) porosity, further referred to as drainage porosity (marked as a difference between total porosity and moisture corresponding to field capacity indicated at -10 kPa potential, which is a corresponding value at pF=2.0, and pores' partial capacity of a diameter over 30 um). Statistical analysis – coefficient of correlation was carried out using the Statistica 12 software system (StatSoft Inc., Tulsa, OK). All results given in the text are mean values from five replicates.

RESULTS AND DISCUSSION

Classification and physical properties of the studied soils

In accordance with the FAO-WRB classification (IUSS Working Group 2015), the studied soils were classified as Gleyic Phaeozem (profile 1 – Szewce), Humic Gleysol (profile 2 – Rudzk Duży), Murshic Sapric Histosol (profile 3 – Rudzk Duży) and Ochric Arenosol (profile 4 – Rudzk Mały). Whereas, in accordance to the Polish Soil Classification (PSC 2011), they were classified to the following subtypes (soil names in Polish): *czarna ziemia glejowa* (profile 1), *gleba torfiasto-glejowa* (profile 2), *gleba organiczna saprowo-murszowa* (profile 3) and Arenosol (profile 4). Soil profiles 2 and 4 were of sandy texture, containing 1–2% of clay and 3–6% of silt, while profile 1 was formed from silty loam containing 6% of clay and 58% of silt, covered by 35 cm of muck material (Table 1).

TABLE 1. TEXTURE OF THE STUDIED SOILS

Object	Profile number	Soil Horizon	Depth (cm)	Percentage content of fraction of diameter: (mm)									Texture acc. FAO (2006)
				2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.10	0.10–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002	
Szewce	1	Au	0–35	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Mursh
		AC	35–58	0.02	0.76	12.12	11.10	12	15	20	23	6	SL
		Cgk	58–150	0.06	1.27	11.30	13.37	10	15	21	22	6	SL
Rudzk Duży	2	Au	5–25	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Mursh
		Cg1	25–35	1.65	2.39	42.56	40.40	5	4	1	1	2	S
		Cg2	35–150	1.04	3.35	39.21	43.40	6	3	1	1	2	S
Rudzk Duży	3	M1	5–25	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Mursh
		M2	25–50	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Mursh
		Oa1	50–75	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Peat
		Oa2	75–150	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Peat
Rudzk Mały	4	Ap	0–20	0.67	6.85	38.48	42.00	7	1	1	1	2	S
		C1	20–45	0.98	8.71	39.20	39.11	7	2	1	1	1	S
		C2	45–65	0.62	10.2	46.08	31.10	7	1	1	1	2	S
		C3	65–150	0.97	11.0	42.53	31.50	7	2	3	1	1	S

Explanation: S – Sand, SL – Silty Loam, n.d. – not determined

Recorded particle density value in organic and organo-mineral horizons was low (1.57–2.35 Mg·m^{-3}). In mineral horizons this property oscillated (in all cases) around the density of quartz, i.e. 2.58–2.65 Mg·m^{-3} (Table 2). Likewise the lowest bulk density and the highest total porosity was observed in soil profile 3, which was formed only from organic materials. In other soils, relatively higher bulk density and, what follows – lower total porosity, were observed in surface horizons as the effect of long-term cultivation and lower content of organic matter. In epipedons, the lowest density – 0.67 Mg·m^{-3}, at porosity – 71.5%v was recorded in profile 2, whereas the highest bulk density: 1.40 Mg·m^{-3}, at the lowest total porosity – 46.9%v, in profile 4. Relating values in endopedons changed gradually along with the increase of depth and oscillated between: bulk density from 1.36 Mg·m^{-3} (horizon Cg1 in profile 2) to 1.62 (horizon C3 in profile 4), at porosity of 48.5–38.8%v, respectively (Table 2). Content of organic matter in soils under study varied within a wide range (0.10–892.0 g·kg^{-1}) and reached the highest values in peat and mursh horizons (profile 3). Among other soil profiles the highest content of organic matter was observed in the surface muck horizons in the profile 1 and 2 (Table 2). The lowest content of organic matter (≤0.20 g·kg^{-1}) were recorded in endopedons of profile 4. Recorded amounts of soil organic matter, both in organic and mineral soils are typical for arable lands. Similar content of organic matter in agricultural managed peat soils in central Poland were reported by Glina *et al.* (2016b). Lower amounts of organic matter in mucks horizons (profile 1 and 2) is the result of mineralization process, typical for drained soils (Kalisz *et al.* 2010, Glina *et al.* 2016a).

TABLE 2. BASIC PHYSICAL AND WATER PROPERTIES OF THE STUDIED SOILS

Profile No.	Soil Horizon	Depth (cm)	Particle density (Mg·m^{-3})	Bulk density (Mg·m^{-3})	Total porosity (%v)	Drainage porosity (%v)	Organic mater (g·kg^{-3})	H (%v)	MH (%v)	SH (µm·s^{-1})
1	Au	0–35	2.58	1.34	48.0	8.3	50.7	7.07	21.6	19.4
	AC	35–58	2.64	1.44	45.5	6.0	8.2	2.38	10.3	2.20
	Cgk	58–150	2.65	1.46	44.9	7.6	1.0	2.12	8.90	1.90
2	Au	5–25	2.35	0.67	71.5	21.9	183	6.78	11.9	14.1
	Cg1	25–35	2.64	1.36	48.5	35.7	1.1	0.75	1.23	109
	Cg2	35–150	2.65	1.64	38.1	28.4	0.7	0.59	0.96	161
3	M1	5–25	1.95	0.54	72.3	10.9	552	7.63	20.4	22.8
	M2	25–50	1.80	0.34	81.1	14.9	684	8.90	23.9	5.40
	Oa1	50–75	1.58	0.29	81.6	8.5	882	11.5	25.8	0.76
	Oa2	75–150	1.57	0.22	85.9	8.8	892	13.1	27.3	0.41
4	Ap	0–20	2.64	1.40	46.9	35.5	7.5	0.73	0.93	176
	C1	20–45	2.65	1.51	43.4	34.1	0.2	0.35	0.75	307
	C2	45–65	2.65	1.59	40.0	31.6	0.2	0.28	0.93	275
	C3	65–150	2.65	1.62	38.8	30.6	0.1	0.25	0.72	236

Explanation: H – hygroscopic water, MH – maximum hygroscopic capacity, SH – saturated hydraulic conductivity

Water properties of the studied soils

Alike bulk density and total porosity, the share of mineral and organic colloids determined the content of hygroscopic water (H) and maximum hygroscopic capacity (MH). The highest values of both parameters were observed in organic and organo-mineral horizons (Table 2). Whereas, in silty loam textured horizons (profile 1) described parameters had lower values. The lowest values of H an MH were observed in sand horizons in profile 2 and 4. Mentioned values varied in the range of 0.25–0.75%v for H and 0.72–1.23%v for MH (Tables 1, 2). Saturated hydraulic conductivity (SH) was strongly differentiated. Its highest values (over 100 $\mu m \cdot s^{-1}$) were observed in sand horizons (profile 2 and 4). The lowest speed of filtration was visible in peat layers, where it oscillated between 0.41 to 0.76 $\mu m \cdot s^{-1}$ (Table 2). SH values were slightly higher in silty loam layers in profile 1: (1.9–2.2 $\mu m \cdot s^{-1}$) and relatively high in mursh (22.8 $\mu m \cdot s^{-1}$, profile 3) and mucky horizons (14.1 $\mu m \cdot s^{-1}$, profile 2) (Table 2).

High bond strength (correlation coefficient = 0.848767) was observed between the saturated hydraulic conductivity and values of drainage porosity, which suggests the suitability of this parameter for characterizing soil water properties (Kaźmierowski *et al*. 2006, Gajewski *et al*. 2007, Spychalski *et al*. 2004, 2007, Kaczmarek *et al*. 2008). The obtained values of correlation coefficient did not differ from the scopes of this parameter in soils of similar origin and texture, previously presented by numerous authors (as: Zawadzki 1999, as: Krogulec 1994, Gajewski *et al*. 2007, Kaczmarek 2001b, Kaczmarek *et al*. 2008).

TABLE 3. SOIL WATER POTENTIALS AND THE TOTAL AND READILY AVAILABLE WATER IN THE STUDIED SOILS

Profile No.	Soil horizon	Depth (cm)	Water capacity at pF: (%v)						TAW (%v) 2.0–4.2	RAW (%v) 2.0–3.7
			0.0	2.0	2.5	3.7	4.2	4.5		
1	Au	0–35	43.27	39.70	28.83	22.89	17.20	13.64	22.50	16.81
	AC	35–58	43.79	39.46	35.48	29.70	16.78	10.35	22.68	9.76
	Cgk	58–150	42.34	37.27	32.46	25.26	14.81	9.07	22.46	12.01
2	Au	5–25	68.01	49.62	40.20	20.53	15.36	9.98	34.26	29.09
	C1g	25–35	45.17	12.77	8.16	4.56	1.67	1.11	11.10	8.21
	C2g	35–150	36.94	9.72	6.24	2.20	1.36	0.97	8.36	7.52
3	M1	5–25	68.28	61.45	54.54	48.81	35.62	20.36	25.83	12.64
	M2	25–50	79.54	66.23	63.47	53.79	29.63	8.60	36.60	12.44
	Oa1	50–75	79.25	73.13	61.27	53.44	37.80	22.28	35.33	19.69
	Oa2	75–150	80.42	77.09	65.70	59.25	40.43	18.14	36.66	17.84
4	Ap	0–20	44.22	11.43	7.15	3.03	1.67	0.99	9.76	8.40
	C1	20–45	41.30	9.28	5.86	1.96	1.17	0.75	8.11	7.32
	C2	45–65	36.81	8.41	4.24	1.91	1.56	0.69	6.85	6.50
	C3	65–150	35.93	8.23	4.73	1.87	1.49	0.64	6.74	6.36

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

In all cases, maximum water capacity was slightly lower (by 2–3%) than total porosity. Therefore, the highest maximum capacity was observed in organic and organo-mineral horizons: from 43.27 (profile 1; Au) to 80.42%v (profile 3; Oa2), whereas the lowest – in sandy endopedons: from 35.93 (profile 4; C3) to 45.17%v (profile 2; C1g). The highest values of field capacity (pF=2.0) were found in peat and mucky horizons: from 39.70 (profile 1; Au to 77.09%v (profile 3; Oa2); in soils with silty loam texture these moisturizes oscillated between about 37–39%v. The lowest field capacity was found in horizons of sandy texture (8.23–12.77%v) (Table 3). Respective values at the potential of 2.5 were lower by several (in case of sapric peat – over a dozen) volume percent. Worth to notice is the relation between the values of water capacity at pF=3.7 (production water point), pF=4.2 (wilting point), texture and organic matter content. At pF=3.7 and 4.2, the lowest amount of water was bound by sands: from 1.87; 1.49%v (horizon C3 in profile 4) to 4.56; 1.67%v (horizon C1g in profile 2). Higher amounts of water were recorded in silty loam horizons: 25.26–29.70%v at pF 3.7 (horizon Cgk; profile 1; horizon AC; profile 1) and 14.81–16.78%v at pF=4.2 – in the same horizons. The above-mentioned values were much higher in organic horizons (pF 3.7: 48.81–59.25 and at pF 4.2: 29.63–40.43) (Table 3). Such distribution of water content at various potential of being bound by soil, may be considered typical and alike ones previously described in papers by Rząsa *et al*. (1999), Kaczmarek (2001a, 2011) and Kaczmarek *et al*. (2000, 2007, 2008), about arable mineral soils. Based on obtained data total and readily available water were calculated (Table 3). Their values were close to the data for soils of similar origin and texture from central Poland described by numerous authors (Rząsa *et al*. 1999, Kaczmarek *et al*. 2000, 2008, Kaczmarek 2001a). These relative indicators were used to estimate real retention abilities of a soil in two layers (0–50 and 0–100 cm) considered as the most important in terms of providing plants with water (Kulhavy 1976, Ślusarczyk 1979).

TABLE 4. RETENTION OF THE SOILS STUDIED

Profile number	Retention at RAV		Retention at TAV	
	in layers		in layers	
	0–50	0–100	0–50	0–100
	(cm)		(cm)	
1	46	103	75	187
2	92	130	109	151
3	63	157	156	336
4	31	65	36	72

The lowest retention was observed in soil profile 4, what resulted from its sandy texture. The retention of soil 1 was much higher, especially in the layer 0–100 cm. Very high retention abilities were determined in soil profiles 2 and 3, due to presence of organic materials (sapric peat) of high water capacities (Tables 3, 4). These soils were able to retain 63–92 mm of production water and 109–156 mm of water potentially available in the layer 0–50 cm, and 130–157 mm of production water and 151–336 mm of potentially available water in the layer 0–100 cm (Table 4). Therefore, they are able to retain even more than a half of annual precipitation in the study area. Calculated retention values were close to those reported by Ślusarczyk (1979) (for arable soils of various texture) and Kaczmarek (2001a), Kaczmarek *et al*. (2008), for Arenosols and Phaeozems.

CONCLUSIONS

The investigated soils present a water-precipitation management type and their productivity fully depends on the sum and distribution of annual precipitation. Changes visible particularly in profiles 2 and 3, as a results of decession, cannot impair their productivity. They were triggered by the above-mentioned natural and anthropogenic (other than mining) factors and only overlap this advanced state of soils degradation. The properties of examined soils are similar to other Polish soils of alike origin, texture and organic matter content. They will not undergo further degradation as a result of being adjacent to the planned exposure of lignite open-cast mining. What is possible and advised, is to exclude them from detailed inventory research, under condition that their characteristics properties are properly documented.

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