SOIL SCIENCE ANNUAL
2020, 71(1), 66–75

https://doi.org/10.37501/soilsa/121493

Selected properties of reclaimed mine soils in the area of a former gravel mine in north-eastern Poland

Sławomir Smólczyński[1,*], Mirosław Orzechowski[1], Barbara Kalisz[1], Krzysztof Krupiński[2]

[1] University of Warmia and Mazury in Olsztyn, Department of Soil Science and Land Reclamation, Plac Łódzki 3, 10–722 Olsztyn, Poland
[2] County Administrator's Office in Nidzica, ul. Traugutta 23, 13-100 Nidzica, Poland

* Dr hab. Sławomir Smólczyński, slawomir.smolczynski@uwm.edu.pl, ORCID iD: https://orcid.org/0000-0001-7643-4284

Received: August 28, 2019
Accepted: February 18, 2020
Associated editor: J. Chojnicki

Keywords

Land reclamation
Anthropogenic soils
Exchangeable cations
Physical properties
Water retention

Abstract

The aim of the research was to compare physico-chemical properties, air-water and water retention properties of soils formed as a result of land reclamation in the area after gravel ex.ploitation with the properties of non-exploited soils. The examined soils had the texture of sand, loamy sand and sandy loam. The average humus stock in anthropogenically shaped soils amounted to 84.75 $Mg \cdot ha^{-1}$, which qualifies as very well reclaimed. In anthropogenic humus horizons, the average volume of mesopores corresponding to the contents of water potentially available (PRU) and easily available to plants (ERU) amounted to 11.16% v/v and 6.95% v/v respectively, with these values being statistically significantly higher than in deeper soil horizons. Humus horizons of reclaimed soils had higher, but not significantly, average values of field water capacity (43.42 mm), PRU (32.31 mm) and ERU (20.16 mm) than natural soils. The soil reaction of reclaimed soils was neutral or alkaline (pH_{KCl} 6.6-7.4). Calcium prevailed as the basic exchangeable cation. The sum of basic cations in humus horizons of reclaimed soils was significantly higher than in deeper horizons. No significant differences were found between grain-size distribution, humus stock, physico-chemical, air-water and water retention properties in reclaimed and non-exploited soils. During technical reclamation, humus horizon was restored, soil properties and soil production potential became similar to soil properties prior to exploitation.

1. Introduction

The development of road infrastructure in Poland is one of the reasons for the growing demand for natural stone. For these reasons, open gravel mines are often established in the vicinity of the planned roads. The opencast aggregate (i.e. gravel and sand) mining method causes a number of changes in the environment, including soil cover degradation, topography and water relation changes. According to the Statistical Yearbook data (website 1), in 2017 the area of land requiring reclamation in Poland amounted to 62,038 ha, while in Warmińsko-Mazurskie Voivodeship it amounted to 4,838 ha (5th position in Poland). This area will most probably increase in the years to come, as by the end of May 2018, among others, the Marshal of the Warmińsko-Mazurskie Voivodeship issued 19 licences for natural aggregate mining in Nidzica County, and the Starost of Nidzica issued an additional 10 licences. According to Polish regulations (Act of 3 February 1995), mining company are required to carry out reclamation when exploitation ceases. It is not uncommon that they fulfil this requirement improperly or only carry out technical treatments to the extent necessary to recieve the decision that reclamation has been completed and then reclassify the land to agricultural or forest land. A Supreme Audit Office (NIK) report indicates numerous irregularities during the reclamation process (website 2). The assignment of a valuation class means land has acquired a proper value, i.e. the conditions provided for in the Act on the protection of agricultural and forest land have been fulfilled (Act of 3 February 1995). However, Mocek-Płóciniak (2014) stressed that the statutory definition of reclamation omits an important aspect of biological reclamation, i.e. the restoration of the soil's biological activity. Gilewska (1991) as well as Gilewska and Otremba (2018) indicate that the condition for proper plant development on reclaimed soil is the restoration of its chemical and physical properties. Physical and water properties, as well as the trophism of anthropogenically shaped soils in areas following aggregate exploitation, are often unfavourable and the soil value is very low (Drab, 2004; Orzechowski et al., 2008; Smólczyński et al., 2010).

The aim of the study was to compare selected physical and chemical soil properties in a former mine area after one year of technical reclamation with the properties of soils not subjected to aggregate exploitation.

2. Study area and methodology

The mining activity covered 103.38 ha, and the aggregate resources were estimated at approx. 10.72 million Mg. The overburden comprised formations with the grain-size distribution of loamy sand, loamy silty sand, sandy silt and loam. Before exploitation, agricultural land within the study area was included as class IVa, IVb, V and VI arable land. More than 80% of this area was covered by soils formed from loamy sand deposited on loose or light loamy sand.

Prior to the commencement of the natural aggregate exploitation, the mining company removed the humus horizon and the overburden layer. For the area under study, the reclamation course was established towards agricultural and forest terrain, including the possibility of developing water reservoirs. Moreover, wastes with the code of 17 05 04, i.e. soil and stones other than those mentioned in 17 05 03 (Regulation of the Council of Ministers of 9 December 2014 on the waste catalog. Journal of Laws of 2014, item 1923) were allowed for the purposes of reclamation.

About half of the mining area (48 ha) has so far been reclaimed. Reclamation treatments had started or exploitation was still being conducted in the remaining areas. Reclamation treatments included proper shaping of land surface along with the formation of small water basins (Fig. 1) using overburdened soil. Humus material of thickness of 26–32 cm was spread onto the soil surface. As part of biological reclamation, a mixture of

Fig. 1. A water body formed during technical reclamation at the Kanigowo VII mine

Fig. 2. Technical reclamation – prisms of humus earth used for reclamation in the Kanigowo VII mine

barley, oats and narrow-leaved lupin was sown in the spring of 2018. The following fertiliser doses were applied per ha: 50 kg N, 40 P_2O_5 and 60 kg K_2O. In the reclaimed area, four soil exposures were made and soil samples were collected from the humus horizon (Apa), the sub-humus horizon to a depth of 50 cm (C1a), the 50–75 cm horizon (C2a) and the 75–100 cm horizon (C3a) in the first year following the performance of biological reclamation. In order to compare the soil properties, four soil exposures were also made in the mining area not yet subjected to exploitation, and soil samples were collected from the same depths (marked as Apn, C1n, C2n, C3n). Additionally, five samples of humus earth (App) stored at the prisms to be later spread over the surface (Fig. 2), were also collected.

In the collected samples, the following analyses were determined: grain-size distribution by the laser diffraction method using a Mastersizer 3000 device; solid phase density by the pycnometric method; bulk density using 100 cm^3 cylinders; total porosity from the calculation based on the solid phase density and bulk density; organic carbon and total nitrogen contents using a CN Vario Max Cube Elementar analyser; pH in H_2O and in 1M KCl by the potentiometric method and the exchangeable base cation content was determined following soil extraction using 0.5 mol dm^{-3} ammonium chloride (NH_4Cl) at the pH of 8.2. Ca^{2+}, Mg^{2+}, K^+ and Na^+ were determined using iCAP 7400 ICP-OES Termo Scientific spectrometer. The humus content was calculated based on the organic carbon content, using the coefficient of 1.724 and the humus stock was calculated on the base of humus content, bulk density and thickness of humus horizon.

Water retention properties of soil formations were determined by the low and high-pressure chamber method (Zawadzki, 1973). Based on the determined value of soil water potential at 98.1 hPa (pF 2.0), 490.5 hPa (pF 2.7), 981.0 hPa (pF 3.0) and 15,547.9 hPa (pF 4.2), the volume of soil pores was calculated according to Zawadzki (1973): macropores = (total porosity – W v/v at pF 2.0), micropores = W v/v at pF 4.2, potential useful retention, PRU = (W v/v at pF 2.0 – W v/v at pF 4.2), effective useful retention, ERU = (W v/v at pF 2.0 – W v/v at pF 3.0), small capillary retention – DKRU = (W v/v at pF 3.0 –W v/v at pF 4.2) and then water resources in humus horizons (Aan, Ap) and in the layers of 0–50 and 0–100 cm.

Statistical calculations (the average value, standard deviation, test of significance for two average values) were conducted using STATISTICA 13 software.

3. Results

Technical reclamation resulted in the development of humus horizons which thickness ranged from 26 to 32 cm and was similar (and occasionally greater) to that in non-exploited soil, where it ranged from 25 to 30 cm (Table 1). Humus horizons of reclaimed soils (Apa) had texture of light loamy sand or loamy sand, similarly to the formations deposited in prisms, while the Apn horizons of non-exploited soils had texture of loamy sand or sandy loam (Table 2). Formations in deeper horizons (C1, C2, C3) in both non-exploited and anthropogenic soils exhibited a greater variability of grain-size distribution and were qualified as loose sand, light loamy sand, loamy sand and sandy loam. Skeletal fraction content was low and ranged, on average, from 3.0 to 5.75% (Table 2). In the analysed formations, the dominant fraction was sand, of which the subfractions of fine sand (ø 0.1–0.25 mm) as well as very fine (ø 0.1–0.05 mm) and medium sand (ø 0.25–0.5 mm) were dominant. No statistically significant differences between fraction contents in reclaimed and non-exploited soils were noted.

Average carbon and nitrogen contents in humus horizons (Apa) of reclaimed soils (C – 11.31 g·kg^{-1}, N – 0.86 g·kg^{-1}) and humus of App in the prisms (C – 11.38 g·kg^{-1}, N – 0.88 g·kg^{-1}) did not differ from the average contents of these elements in non-exploited soils (C – 10.91 g·kg^{-1}, N – 0.90 g·kg^{-1}). What was characteristic in the an-

Table 1.
Average carbon and nitrogen contents of humus horizons

		C	N	C:N	Humus	N	Thickness of humus horizon
Horizon	Parameter	g·kg^{-1}			Mg·ha^{-1}		cm
1 Apa	X	11.31	0.86	13.3	84.75	3.72	26–32
	SD	1.30	0.14	0.78	11.40	0.74	
	CV	11.48	16.29	5.87	13.45	19.89	26–32
2 App	X	11.38	0.88	12.90			
	SD	1.39	0.09	0.57			
	CV	12.25	10.48	4.45			
3 Apn	X	10.91	0.90	12.10	88.63	4.25	25–30
	SD	1.58	0.12	0.44	20.93	0.94	
	CV	14.50	13.74	3.60	23.62	22.18	
		Significance of differences			Insignificant differences		

Apa – anthropogenic humus horizon, App – humus horizon from the prism, Apn – non-exploited soil humus horizon, X – average value, SD – standard deviation, CV – coefficient of variance

Table 2.
Particle-size distribution of the analysed soils

		Percentage content of diameter fractions in mm											Grain-size distribution
Horizon	Parameter	> 2.0	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	Sand 2.0–0.05	0.05–0.02	0.02–0.002	Silt 0.05–0.002	Clay < 0.002	
1Apa	X	4.00	0.25	9.05	22.20	28.63	19.38	79.50	12.63	7.68	20.30	0.20	ps, pg
	SD	0.82	0.21	5.63	2.44	2.47	3.50	5.64	3.31	2.26	5.53	0.14	
	CV	20.41	83.27	62.22	11.00	8.64	18.06	7.10	26.22	29.43	27.26	70.71	
2C1a	X	4.50	0.20	11.38	22.25	28.80	20.95	83.53	12.10	4.38	16.48	0.00	pg, ps
	SD	0.58	0.20	2.81	5.15	5.42	6.55	0.94	1.64	0.92	0.94	0.00	
	CV	12.83	100.00	24.69	23.16	18.81	31.28	1.13	13.55	21.06	5.72	0.0	
3C2a	X	5.75	0.55	14.53	18.30	24.28	23.50	81.15	12.55	6.18	18.73	0.13	ps, pg, gp
	SD	0.50	0.68	6.32	2.99	2.78	4.36	9.50	5.89	3.68	9.38	0.15	
	CV	8.70	123.76	43.54	16.34	11.47	18.55	11.70	46.91	59.62	50.07	120.00	
4C3a	X	5.00	2.13	17.75	26.25	23.00	19.45	88.58	8.65	2.70	11.35	0.10	pl, ps, pg
	SD	0.50	0.68	6.32	2.99	2.78	4.36	9.50	5.89	3.68	9.38	0.15	
	CV	10.00	32.03	35.63	11.39	12.10	22.41	10.72	68.06	136.36	82.61	150.00	
5App	X	3.60	1.10	14.86	24.94	24.94	18.04	83.88	11.28	4.66	15.94	0.18	ps, pg
	SD	1.14	0.57	5.50	5.53	3.24	7.41	4.71	3.76	1.34	4.57	0.30	
	CV	31.67	51.43	37.02	22.16	12.99	41.09	5.61	33.34	28.77	28.66	168.51	
6Apn	X	3.00	0.33	11.23	19.45	28.18	18.58	77.75	14.28	7.28	21.55	0.70	pg, ps
	SD	0.82	0.38	4.20	4.37	4.45	3.23	9.71	5.26	4.21	8.79	0.97	
	CV	27.22	116.15	37.38	22.48	15.78	17.39	12.49	36.82	57.90	40.81	138.51	
7C1n	X	4.75	1.10	11.20	22.93	24.53	17.50	73.48	16.70	9.03	25.73	0.80	ps, pg, gp
	SD	0.96	1.51	4.87	5.65	5.35	3.70	11.70	4.51	6.87	11.27	0.70	
	CV	20.16	137.27	43.51	24.63	21.81	21.12	15.92	27.00	76.12	43.80	87.20	
8C2n	X	5.25	0.53	10.80	19.33	20.75	19.70	74.88	15.35	8.80	24.15	0.98	pg, gp
	SD	0.50	0.57	5.05	3.06	3.78	3.39	10.93	5.51	4.91	9.53	1.82	
	CV	9.52	109.28	46.77	15.82	18.21	17.20	14.59	35.92	55.81	39.45	186.58	
9C3n	X	5.00	0.98	19.38	24.50	28.10	15.10	88.05	8.63	3.33	11.95	0.00	pl, ps, pg
	SD	1.15	1.13	6.02	7.24	5.41	3.74	4.61	3.69	1.11	4.61	0.00	
	CV	23.09	115.55	31.08	29.56	19.26	24.74	5.23	42.75	33.52	38.56	0.00	
Significance of differences		6<7	1<5, 2<3			6>7				1>2, 1>5		1>2	

pl–loose sand, ps–light loamy sand, pg–, loamy sand, gp–sandy loam

Table 3.
Physical and air-water properties of the analysed soils

Horizon	Parameter	Solid phase density	Bulk density	Total porosity	pF 2.0	Macropores	PRU	ERU	DKRU	Micropores
		Mg·m^{-3}		% v/v						
1 Apa	X	2.62	1.50	42.64	15.00	27.11	11.16	6.95	4.21	4.38
	SD	0.03	0.04	1.74	0.95	0.66	0.68	0.13	0.56	0.93
	CV	1.14	2.48	4.08	6.32	2.45	6.07	1.86	13.34	21.23
2 C1a	X	2.62	1.54	41.44	12.85	27.93	9.09	5.00	4.09	4.43
	S	0.02	0.03	1.47	2.14	2.25	1.23	0.80	1.27	1.68
	V	0.76	1.96	3.56	16.64	8.06	13.53	16.08	31.04	37.97
3 C2a	X	2.63	1.58	39.72	13.68	26.05	8.50	4.38	4.13	5.18
	SD	0.03	0.05	1.52	3.08	3.98	1.60	1.28	0.33	2.44
	CV	1.14	2.89	3.81	22.53	15.30	18.85	29.35	8.01	47.21
4 C3a	X	2.66	1.60	39.66	10.53	29.13	6.98	3.63	3.35	3.55
	SD	0.01	0.07	2.45	2.73	1.92	2.22	1.72	0.81	0.99
	CV	0.37	4.22	6.18	25.91	6.58	31.89	47.48	24.19	27.84
5 App	X	2.65	1.58	40.44	13.32	27.12	8.82	5.58	3.24	4.50
	SD	0.02	0.08	3.48	2.76	2.94	2.68	1.59	1.10	1.12
	CV	0.77	5.38	8.62	20.73	10.84	30.44	28.49	33.92	24.99
6 Apn	X	2.65	1.71	35.46	15.40	20.06	10.20	6.45	3.75	5.20
	SD	0.02	0.04	1.47	2.85	4.20	1.29	0.79	0.81	2.54
	CV	0.77	2.05	4.15	18.50	20.96	12.63	12.17	21.61	48.93
7 C1n	X	2.65	1.69	36.03	15.63	20.41	9.83	5.68	4.15	5.80
	SD	0.04	0.02	1.51	2.87	4.27	1.09	1.05	0.50	1.82
	CV	1.42	1.01	4.18	18.39	20.91	11.10	18.50	12.05	31.35
8 C2n	X	2.65	1.72	35.13	14.53	20.61	8.88	4.68	4.20	5.65
	SD	0.02	0.04	1.78	1.30	2.66	1.56	1.23	0.39	0.78
	CV	0.72	2.10	5.08	8.93	12.90	17.61	26.28	9.32	13.75
9 C3n	X	2.63	1.64	37.65	9.95	27.28	7.10	3.88	3.22	3.28
	SD	0.03	0.04	1.84	3.39	3.75	2.70	1.52	1.19	0.98
	CV	1.14	2.62	4.89	34.08	13.76	38.05	39.33	36.97	29.85
Significance of differences			2<7, 3<8, 5<6	2>7, 3>8, 5>6	8>9	2>7, 5>6, 8<9	1>2	1>2		8>9

PRU – potential useful retention – potentially available water; ERU – effective useful retention – easily available water; DKRU – small capillary retention – small pore water capacity

alysed formations was the narrow C:N ratio ranging from 12 to 13 (Table 1). The soils developing as a result of long-term reclamation treatments on post-mining area of the Pątnów brown coal open pit were also characterised by a narrow C:N ratio. However, their carbon and nitrogen contents were lower than those in the soils of the analysed Kanigowo mine (Gilewska and Otremba, 2004; Spychalski et al., 2016). The average humus stock (84.75 Mg·ha^{-1}) and nitrogen stock (3.72 Mg·ha^{-1}) in reclaimed soils were less than those in non-exploited soils (88.63 Mg·ha^{-1} and 4.25 Mg·ha^{-1}, respectively) though the differences were not statistically significant. Taking into account humus stock and the humus horizon depth, the soils under study qualify as very well reclaimed soils according to Siuta et al. (1985). However, technical reclamation of this type of land is not always so effective. In anthropogenic soils of a similar type, the humus horizon thickness ranged from 18 to 22 cm, the humus stock was 1.5–2 times lower and total nitrogen stock was up to three times lower (Orzechowski et al., 2008).

Reclaimed soils were characterised by more favourable physical properties than non-exploited soils in which the bulk density in the Apn, C1n and C2n horizons was statistically significantly higher and total porosity was significantly lower than in the Apa, C1a and C2a horizons (Table 3). Air pores were dominant within the soil pores and their volume exceeded the volume of mesopores from 1.5 times in Apa horizon to 4 times in the C3a horizon. The average macropore volume was the lowest in the horizons (Apn, C1n and C2n) of non-exploited soils, which is the result of

Table 4.
Retention properties of the analysed soils

Horizon	Parameter	Field water capacity pF 2.0	Macropores	PRU	ERU	DKRU	Micropores
Water retention in the 0–30 cm layer [mm]							
1 Apa	X	43.42	78.61	32.31	20.16	12.16	12.81
	SD	3.66	7.23	3.02	1.83	1.65	3.71
	CV	8.43	9.20	9.35	9.10	13.54	28.96
2 Apn	X	42.18	54.32	27.72	17.59	10.13	14.47
	SD	10.17	10.33	3.22	2.65	1.75	8.25
	CV	24.11	19.02	11.61	15.06	17.30	57.04
Significance of differences			1>2				
Water retention within the 0–50 cm layer [mm]							
1	X	70.70	136.97	51.46	30.56	20.90	22.22
	SD	6.39	4.84	3.46	1.82	4.07	5.20
	CV	9.04	3.53	6.72	5.95	19.45	23.42
2	X	77.52	101.04	50.01	30.52	19.50	27.50
	SD	14.18	21.09	4.82	4.41	1.49	11.03
	CV	18.29	20.87	9.64	14.47	7.63	40.11
Significance of differences			1>2				
Water retention within the 0–100 cm layer [mm]							
1	X	124.83	263.43	101.52	53.06	40.97	43.97
	SD	9.51	18.13	29.11	8.31	6.36	9.18
	CV	7.61	6.88	28.67	15.66	15.52	20.88
2	X	138.70	220.76	89.95	51.89	38.05	49.82
	SD	16.54	29.97	13.01	9.36	4.54	10.21
	CV	11.93	13.58	14.46	18.04	11.93	20.49
Significance of differences			1>2				

1 – reclaimed soils, 2 – non-exploited soils,

their higher compaction degree. No significant differences were noted between the average mesopore and micropore volume and the water content at the potential value of 98.1 hPa (pF 2.0) corresponding to the field water capacity in reclaimed and non-exploited soils (Table 3). In the anthropogenic Apa horizons, the average mesopore volume corresponding to the content of water available (PRU) and easily available to plants (ERU) was statistically significantly higher than in deeper layers, which proves the important role of the humus horizon in shaping the air and water relationships. In the analysed Apa, Apn and App humus horizons, the volume of water easily available to plants (ERU) was higher by an average of 2.34–2.74% v/v than the volume hardly available to plants (DKRU), while in deeper horizons (C1, C2, C3) the differences were smaller and did not exceed 1%.

Table 4 presents the average retention properties in the humus 0–50 cm and 0–100 cm horizons expressed in mm. In the humus horizon of reclaimed soils, the average values of field water capacity (43.42 mm), PRU (32.31 mm) and ERU (20.16 mm) were higher than those in non-exploited soils (42.18, 27.72 and 17.59 mm respectively). However, the differences were not statistically significant. Similar relationships were noted in the remaining analysed horizons. Compared to non-exploited soils, only the gravitational water content was significantly higher in the humus horizon and in the 0–50 cm horizon in reclaimed soils. Water content at pF 2.0, potential useful retention (PRU) and effective useful retention (ERU) were positively correlated with the silt fraction content and were negatively correlated with the sand fraction content (Table 5). It should be stressed that the content of water potentially available to plants, corresponding to the potential useful retention (51.46 mm) and effective useful retention (30.56 mm) in the 0–50 horizon in the analysed reclaimed soils, was 1.5–2 times higher than in post-mining soils of Sarnowo aggregate mine (Smólczyński et al., 2010), while water retention at pF 2.0, corresponding to the field water capacity (70.70), was 2-3 times higher.

The soil reaction of reclaimed soils was either neutral or alkaline (pH KCl of 6.6–7.4), while in non-exploited soils it was slightly acidic or neutral (pH KCl of 6.4–7.10) (Table 6). The carbonate content ranged from trace amounts to 2%. Only in one profile of non-exploited soil was there no carbonates in the humus horizon.

During the reclamation of sandy formations, soil sorptive properties of post-mining area are of particular significance, as stressed by Drab and Greinert (2011). According to these authors, these properties can be regarded as part of the assessment of reclamation treatment effectiveness. Among the exchangeable base cations in the sorption complex of the soils under study, calcium cation was dominant (Table 6), with its content in humus horizons (Apa, App, Apn) ranging from 8.27 to 9.38 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$ of soil, while it ranged from 6.98 to 8.28 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$ of soil in deeper hori-

Table 5.
Correlation coefficients for granulometric fraction contents and soil retention properties

Content of fraction with a diameter of	Total orosity	pF 2.0	Macropores	PRU	ERU	DKRU	Micropores
[mm]	% v/v						
> 2.0	–0.036	–0.335*	0.203	–0.326	–0.435*	–0.039	–0.220
2.0–1.0	–0.073	–0.195	0.089	–0.141	–0.154	–0.073	–0.213
1.0–0.5	0.066	–0.723*	0.504*	–0.624*	–0.626*	–0.420*	–0.476*
0.5–0.25	0.106	–0.609*	0.451*	–0.444*	–0.346*	–0.467*	–0.477*
0.25–0.1	0.191	–0.108	0.215	0.035	0.097	–0.081	–0.263
0.1–0.05	0.244	0.360*	–0.049	0.398*	0.288	0.457*	0.113
0.05–0.02	0.341*	0.764*	–0.731*	0.526*	0.493*	0.414*	0.689*
0.02–0.002	0.340*	0.705*	–0.694*	0.402*	0.400*	0.277	0.743*
< 0.002	–0.423*	0.387*	–0.546*	0.074	0.068	0.061	0.584*
2.0–0.05	0.375*	–0.769*	0.759*	–0.476*	–0.456*	–0.357*	–0.761*
0.05–0.002	0.359*	0.780*	–0.756*	0.499*	0.478*	0.374	0.754*

* significance level at α = 0.05

Table 6. The pH values and exchangeable cation content

	pH			Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	Ca/ Mg	Ca+Mg /K+Na
Horizon	H_2O	KCl	Parameter	cmol$_{(+)}$·kg^{-1} of soil						
1 Apa	7.0–7.4	6.6–6.8	X	9.38	0.78	0.09	0.09	10.33	12.1	58.2
			S	0.57	0.07	0.01	0.01	0.52	1.8	4.5
			V	6.11	9.41	9.07	15.19	5.06	14.6	7.7
2 C1	7.2–7.7	6.7–6.8	X	7.11	0.65	0.07	0.10	7.92	12.1	46.5
			S	0.75	0.22	0.02	0.03	1.01	4.3	6.1
			V	10.57	34.45	23.56	30.63	12.69	35.5	13.1
3 C2	7.3–8.0	6.9–7.3	X	7.22	0.49	0.08	0.08	7.86	15.6	52.1
			S	1.97	0.22	0.03	0.03	2.24	2.5	12.7
			V	27.36	45.73	38.53	39.94	28.52	16.3	24.3
4 C3	7.3–8.1	6.9–7.4	X	6.97	0.42	0.05	0.15	7.59	16.60	36.95
			S	1.50	0.18	0.02	0.17	1.82	3.70	18.3
			V	21.52	42.28	43.20	117.38	23.98	29.0	45.6
5App	7.0–7.3	6.6–6.9	X	8.74	0.68	0.09	0.10	9.62	13.2	50.5
			S	1.24	0.16	0.04	0.02	1.39	2.4	8.9
			V	14.23	23.27	44.42	20.00	14.44	18.5	17.7
6 Apn	6.9–7.2	6.4-6.7	X	8.27	0.85	0.10	0.10	9.31	9.7	47.5
			S	1.49	0.03	0.04	0.02	1.56	1.5	4.4
			V	18.07	3.04	36.86	17.52	16.75	15.8	9.2
7 C1n	7.1–7.2	6.7–6.9	X	8.28	0.71	0.10	0.26	9.35	11.8	42.9
			S	1.48	0.06	0.04	0.36	1.30	2.6	27.3
			V	17.83	8.98	38.91	140.50	13.89	22.1	63.7
8 C2n	7.2–7.3	6.7–6.9	X	7.38	0.73	0.09	0.31	8.51	10.2	32.8
			S	1.14	0.08	0.03	0.39	1.21	0.5	17.4
			V	15.47	10.83	28.43	127.16	14.22	5.4	53.0
9 C3n	7.1–7.4	6.8–7.1	X	6.02	0.39	0.05	0.31	6.77	18.00	20.58
			S	2.03	0.15	0.02	0.28	2.30	0.8	20.2
			V	33.72	37.79	42.24	92.03	33.97	6.4	77.4
Significance of differences				1>2	6>7			1>2	3>8, 5>6, 8<9	1>2, 1>6

TEB – total exchangeable base cations

Table 7.
Correlation coefficients between exchangeable cation and granulometric fraction content

Content of fraction with a diameter of	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	S	$\frac{Ca^{2+}}{Mg^{2+}}$	$\frac{Ca^{2+}+Mg^{2+}}{K^{+}+Na^{+}}$
[mm]	$cmol_{(+)}\cdot kg^{-1}$						
> 2.0	–0.449*	–0.573*	–0.377*	0.124	–0.461*	0.344*	–0.139
2.0–1.0	–0.294	–0.309	–0.233	0.060	–0.298	0.039	–0.147
1.0–0.5	–0.597*	–0.610*	–0.612*	–0.029	–0.620*	0.211	0.001
0.5–0.25	–0.449*	–0.383*	–0.524*	0.075	–0.450*	0.022	–0.097
0.25–0.1	–0.081	0.016	–0.156	0.179	–0.058	–0.045	–0.145
0.1–0.05	0.272	0.162	0.230	–0.027	0.266	0.123	0.114
0.05–0.02	0.659*	0.647*	0.688*	–0.120	0.666*	–0.244	0.134
0.02–0.002	0.535*	0.529*	0.734*	–0.117	0.542*	–0.191	0.048
< 0.002	0.394*	0.377*	0.561*	–0.018	0.405*	–0.135	–0.050
2.0–0.05	–0.636*	–0.625*	–0.754*	0.120	–0.644*	0.231	–0.091
0.05–0.002	0.638*	0.629*	0.749*	–0.126	0.647*	–0.233	0.102

* significance level at α=0.05

zons (C). Magnesium cation content was lower by 9.7–18.0 times than the calcium content. Exchangeable potassium content did not exceed 0.1 $cmol_{(+)}\cdot kg^{-1}$ of soil, and sodium cation content varied greatly ranging from 0.08 to 0.31 $cmol_{(+)}\cdot kg^{-1}$ of soil. Spychalski and Gilewska (2008) found that K^{+} content was higher than the Mg^{2+} content in aqueous soil solutions of post-mining area with the texture of light loams. Total base cation content in reclaimed soils in Apa horizons was significantly higher than that in deeper horizons (C1a, C2a, C3a). In non-exploited soils, average TEB (total exchangeable base cations) values in the Apn and C1n horizons were similar, while in the C2n and C3n horizons they were lower. However, these differences were not statistically significant. The ratio of total divalent cations (Ca^{2+}, Mg^{2+}) to monovalent cations (K^{+}, Na^{+}) was wide and ranged from 20.58 to 58.2. The exchangeable cation content exhibited no significant differences between reclaimed and non-exploited soils (Table 6). The base cation content exhibited a positive correlation with the silt fraction and a negative correlation with the sand fraction content (Table 7).

4. Discussion

The conducted study demonstrated that the physico-chemical, as well as air-water and retention properties of reclaimed and non-exploited soils, exhibited no significant statistical differences. A significant role in shaping of soil properties in post-mining areas is played by humus horizon formed as a result of reclamation treatments, which was also confirmed by other studies (Orzechowski et al., 2008; Smólczyński et al., 2010). In the soils developing from the earth following aggregate exploitation, the authors did not find a significant effect of passing time since the completion of reclamation treatments on the rate of soil-forming processes or the development of soil properties. Shrestha and Lal (2010) noted that the rate of carbon and nitrogen sequestration peaked at 10-15 years of reclamation for it to later decline. Wójcik and Krzaklewski (2007) demonstrated that the process of carbon and nitrogen accumulation in reclaimed soil is the slowest in sandy formations. Carbon and nitrogen stock may decrease by 83% and 75% respectively as compared to undisturbed soils (Shrestha and Lal, 2011). According to Orzechowski et al. (2008), soils developing from this kind of soil formation are characterised by a wide C:N ratio exeeding 20. According to Gilewska and Otremba (2005), the rate of pedogenic processes is mainly determined by the improvement of chemical properties. However, as demonstrated by research conducted in the Konin and Turek Brown Coal Field, only long-term agricultural use had a positive effect on the properties of soils in post-mining areas. According to Stachowski and Szafrański (2006), during the first five years following reclamation, the process of organic matter accumulation in post-mining soil formations with a loamy texture, despite the introduction of straw and post-harvest remnants into the soil, was minor and amounted to 0.002 $g\cdot kg^{-1}$. After twenty years of reclamation, Gilewska and Otremba (2004) noted an increase of carbon in the ploughing horizon ranging from 3.5 to 4.1 $g\cdot kg^{-1}$ depending on the fertilisation level. On the other hand, carbon content of 9.8 $g\cdot kg^{-1}$, i.e. at a level similar to the content in reclaimed soils analysed in this study, was obtained only after thirty years of agricultural use (Otremba, 2011). Mukhopadhyay and Masto (2016) found that the carbon stock increased from 1.19 to 9.82 tonnes per hectare during sixteen years. The study results also indicate that, similarly to the process of carbon accumulation, the time factor also plays a role in the shaping physico-chemical properties of reclaimed post-mining area of the Konin Brown Coal Mine. After 5–8 years, the changes were minor (Stachowski and Szafrański, 2006; Gilewska and Otremba, 2008), but the studies of Ahrestha and Lal (2011) revealed higher bulk density by 54% in reclaimed than undisturbed soils. The improvement of soil structure and the related changes in soil pore volume, which result in an increase in potential and effective useful retention, are a long-term process in which the positive effects of the applied reclamation factors, i.e. the fertilisation and crop rotation, were also revealed (Gilewska and Otremba, 2004; Otremba et al., 2015; Pihlap et al., 2019).

The conducted study showed that in reclaimed soil, the physical, water and sorption properties were more favourable in the anthropogenic humus than in deeper horizons. It can, therefore, be concluded that in the process of land reclamation for agricultural purposes, the technical reclamation phase developing the humus horizon plays a significant role. It should be stressed that in the assessment of reclaimed soil value in the soil valuation classification, great importance is attached to the thickness of this horizon (Regulation of the Council of Ministers of 12 September 2012 on soil classification of land).

However, the effects of reclamation treatments depend on the available resources of humus earth of an appropriate quality, which is often lacking if there is no opportunity to replenish it from beyond the mining plant.

5. Conclusions

In reclaimed soils, the contents of water available (PRU) and easily available to plants (ERU), and the base cation content of humus horizons, were statistically significantly higher than that in deeper horizons.

No significant differences were found between the grain-size distribution, humus stock, and the physico-chemical, air-water and retention properties in reclaimed and non-exploited soils.

The mine under study may serve as an example of correctly conducted technical reclamation treatments resulting in a properly shaped surface, including the possibility of water retention in the formed reservoirs, with soils restored by technical methods having acquired potential production possibilities similar to those for soils prior to exploitation.

References

Act of 3 February 1995 on the protection of agricultural and forest land. Journal of Laws of 2017, item 1161. 2.

Drab, M., 2004. The influence of land reclamation activity on forming of selected properties of grounds that had originated as a result of natural aggregate mining in Dobroszów region of Lubuskie province. Roczniki Gleboznawcze–Soil Science Annual 55(2), 85–94. http://ssa.ptg.sggw.pl/files/artykuly/2004_55/2004_tom_55_nr_2/tom_55_nr_2_85-94.pdf3

Drab, M., Greinert, A., 2011. Improvement of the sorption properties of post-mining soils following effective reclamation. Roczniki Gleboznawcze–Soil Science Annual 62(2), 61–68. http://ssa.ptg.sggw.pl/files/artykuly/2011_62/2011_tom_62_2/tom_62_2_061-068.pdf4

Gilewska, M., Otremba, K., 2004. The properties of soils formed from post-mining soil. Roczniki Gleboznawcze–Soil Science Annual 55(2), 111–121. http://ssa.ptg.sggw.pl/files/artykuly/2004_55/2004_tom_55_nr_2/tom_55_nr_2_111-121.pdf

Gilewska, M., Otremba, K., 2005. The influence of reclamation measures on the rate of soil formation processes. Zeszyty Problemowe Postępów Nauk Rolniczych 506,157–164.

Gilewska, M., Otremba, K., 2008. Influence of fodder utilization system on selected physical properties of soils developing on the basis of post-mining grounds. Zeszyty Problemowe Postępów Nauk Rolniczych 526, 163–170.

Gilewska, M., Otremba, K., 2018. The some aspects of agricultural reclamation the post-mining grounds of the Konin and Adamów Brown Coal Mines. Inżynieria Ekologiczna 19(4), 22–29. https://doi.org/10.12912/23920629/93486

Mocek-Płóciniak, A., 2014. Biological reclamation of areas degraded after the excavation of lignite and copper ores. Nauka Przyroda Technologie 8(3), 1–9.

Mukhopadhyay, S., Masto, R.E., 2016. Carbon storage in coal mine spoil by Dalbergia sissoo Roxb. Geoderma 284, 204-213. https://doi.org/10.1016/j.geoderma.2016.09.004

Otremba, K., Gilewska, M., Mocek, A., Owczarzak, W., Gajewski, P., Kaczmarek, Z., 2015. Physical and water properties of soils developing from postmining materials of Konin brown coal mine. Fresenius Environmental Bulletin 24(4), 1227–1231.

Otremba, K. 2011. Selected physical properties of soils developing from post-mining materials of the "Konin" brown coal mine. Roczniki Gleboznawcze–Soil Science Annual 62(2), 305–310. http://ssa.ptg.sggw.pl/files/artykuly/2011_62/2011_tom_62_2/tom_62_2_305-310.pdf

Orzechowski, M., Smólczyński, S., Wyrzykowski, A., 2008. Soil properties of reclaimed sites of sand and gravel post-mine "Sarnowo" in mazowieckie voivodeship. Roczniki Gleboznawcze–Soil Science Annual 59(2), 170–176. http://ssa.ptg.sggw.pl/files/artykuly/2008_59/2008_tom_59_nr_2/tom_59_nr_2_170-176.pdf

Pihlap, E., Vuko, M., Lucas, M., Steffens, M., Schloter, M., Vetterlein, D., Endenich, M., Kögel-Knabner, I., 2019. Initial soil formation in an agriculturally reclaimed open-cast mining area - the role of management and loess parent material. Soil and Tillage Research 191, 224–237, https://doi.org/10.1016/j.still.2019.03.023.

Regulation of the Council of Ministers of 12 September 2012 on soil classification of land. Journal of Laws of 2012, item 1246.

Regulation of the Council of Ministers of 9 December 2014 on the waste catalog. Journal of Laws of 2014, item 1923.

Shrestha, R.K., Lal, R., 2010. Carbon and nitrogen pools in reclaimed land under forest and pasture ecosystems in Ohio, USA. Geoderma 157, 3-4:196-205. https://doi.org/10.1016/j.geoderma.2010.04.013

Shrestha, R.K., Lal, R., 2011. Changes in physical and chemical properties of soil after surface mining and reclamation. Geoderma 161, 168-176. https://doi.org/10.1016/j.geoderma.2010.12.015

Siuta J., Zielińska, A., Makowiecki, K., 1985. The degradation of Earth. Degradacja ziemi. Institute for Environmental Development, Warszawa, 318 p.

Smólczyński, S., Orzechowski, M., 2010. Water capacity and content of exchangeable cations in the soils of reclaimed sand and gravel post-mine areas. Roczniki Gleboznawcze–Soil Science Annual 61(3), 111–120. http://ssa.ptg.sggw.pl/files/artykuly/2010_61/2010_tom_61_3/tom_61_3_111-120.pdf

Spychalski, W., Gilewska, M., 2008. Some chemical properties of soil formed from postmining grounds. Roczniki Gleboznawcze–Soil Science Annual 59 (2), 207–214. http://ssa.ptg.sggw.pl/files/artykuly/2008_59/2008_tom_59_nr_2/tom_59_nr_2_207-214.pdf

Spychalski, W., Mocek, A., Gilewska, M., Owczarzak, W., Otremba, K., 2016. Possibilities of reclamation and agricultural use of land on the example of experiment carried out at brown coal mine of Pątnów. Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu. 136 p.

Stachowski, P., Szafrański, Cz., 2006. The effect of agricultural reclamation on properties of postmining grounds. Roczniki Gleboznawcze–Soil Science Annual 57(1/2), 177–182. http://ssa.ptg.sggw.pl/files/artykuly/2006_57/2006_tom_57_nr_1-2/tom_57_nr_1-2_177-182.pdf

website 1. https://www.google.com/search?client=firefox-b-d&channel=crow&q=rocznik+statystyczny+wojew%C3%B3dztw%2C+-gus%2C+warszawa+2018

website 2. https://www.nik.gov.pl/plik/id,19746,vp,22360.pdf

Wójcik J., Krzaklewski W., 2007. Accumulation of organic matter in the initial soils on the external waste heap of the "Adamów" lignite mine. Roczniki Gleboznawcze–Soil Science Annual 58 (3/4), 151–159. http://ssa.ptg.sggw.pl/files/artykuly/2007_58/2007_tom_58_nr_3-4/tom_58_nr_3-4_151-159.pdf

Zawadzki, 1973. Laboratory analyses of soil water retention. Wiad. IMUZ 11(2), 11–31.

Wybrane właściwości rekultywowanych gleb pogórniczych na terenie kopalni żwiru w północno-wschodniej Polsce

Słowa kluczowe

Rekultywacja gruntów
Gleby antropogeniczne
Kationy wymienne
Właściwości fizyczne
Retencja wody

Streszczenie

Celem badań było porównanie właściwości fizyko-chemicznych, właściwości wodno-powietrznych i retencyjnych gleb powstałych w wyniku rekultywacji terenu po eksploatacji żwiru z właściwościami gleb nieeksploatowanych Badane gleby wykazywały uziarnienie piasków gliniastych, piasków gliniastych pylastych i glin piaszczystych. Średnie zasoby próchnicy w poziomach powierzchniowych wynosiły 84,75 $\mathrm{Mg \cdot ha^{-1}}$, co kwalifikuje je jako bardzo dobrze zrekultywowane. W poziomach próchnicznych zawartość wody potencjalnie dostępnej (PRU) i łatwo dostępnej dla roślin (ERU) wyniosła odpowiednio 11,16% obj. i 6,95% objętościowych, a wartości te były statystycznie istotnie większe niż w głębszych poziomach glebowych. Poziomy próchniczne gleb rekultywowanych miały wyższe, ale nie istotne, średnie wartości polowej pojemności wodnej (43,42 mm), PRU (32,31 mm) i ERU (20,16 mm) niż gleby nie eksploatowane. Odczyn badanych gleb był obojętny lub zasadowy (pH KCl 6,6–7,4). Suma kationów zasadowych, wśród których dominował wapń, w poziomach próchnicznych rekultywowanych gleb była istotnie statystycznie większa niż w poziomach głębszych. Nie stwierdzono natomiast istotnych różnic między uziarnieniem, zasobami próchnicy, właściwościami fizyko-chemicznymi, powietrzno-wodnymi oraz retencyjnymi w glebach rekultywowanych i nie eksploatowanych. Podczas rekultywacji technicznej przywrócono poziom próchniczny, a właściwości gleby i potencjalne zdolności produkcyjne gleb były zbliżone do właściwości gleb przed eksploatacją.