Roman Bykov*, Teresa Eckes**, Maria Trafas**

Quality Assessment of Reclaimed Disposal Areas of Strip Mines, by Example of Piaseczno Mine Dump

1. Introduction

The problem of quality assessment of soil emerges in many cases. The need to assess the quality of arable and forested areas has for long been known and recognised, since it gives an indication of their productivity and allows to determine the tax due, calculation of the property price etc. This method has legal grounds and is based on a specific methodology. The situation is slightly different in case of the reclaimed areas. Although the question on how to evaluate them persists, no unambiguous methods in that domain have been developed yet. There are also no uniform rules and criteria to evaluate the quality of reclaimed land and the reclamation alone. There is also a need to develop such evaluation system that could allow the "transition" from the evaluation of reclaimed land to the system of classification of mature soil.

The assessment of land subject to reclamation must take account of the quality of soil, and the land formation (hills, trough, slope, share of horizontal area etc.). Despite numerous attempts, no such system of assessment has been developed in Poland that would be deemed unambiguous and generally applicable [8, 12, 15]. In case of reclaimed formations being evaluated, firstly such features should be considered that are most important in terms of the completion of the reclamation, with particular attention to such properties which may hinder them the most. In case of the assessment of the reclaimed land, the main attention should be drawn to such features which describe the productivity of the created area for the natural use.

Also, the choice of the analytic method is important, as it should ensure reliable and repeatable results to be obtained and, at the same time, should be

* ELTERMA S.A. SECO/WARWICK Group
** Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow

relatively easy and cost-effective. In case of the reclaimed land, samples should be collected systematically, since it is impossible to manage the variability of features related to e.g. the location, as this is the case of soil. Variability of soils is often incidental, both vertical and horizontal, therefore distribution of formations on the reclaimed land requires a great number of samples to be collected, especially in case of large areas.

2. Main Assessment of Soil Components

In practice so far, the examination of physical properties of reclaimed formations was limited to the determination of soil texture. Other properties (porosity calculated based on the knowledge of the specific and bulk density and consistency limits) are usually not determined, or, if so, for very few samples. As far as the chemical properties are concerned, usually the reaction, available P, K, Mg formation, hydrolytic and exchangeable acidity are determined.

2.1. Soil Texture

The determination of the soil texture is, beyond all doubt, the basic testing method allowing to draw conclusions as to the potential and obstacles in the agricultural use and productivity of the reclaimed land. However, in case of "raw" soil mined during the exploitation from other geochemical zone, the possibility that differences in relation to soil of analogical composition may occur should always be taken into consideration. This applies even more to the technogenic formations, having the features acquired during the technical processes (pulverisation and combustion). A good example here, is the fine, postflotation sludge, of granular composition matching the clay, silty clay or silty clay loam. Whereas other physical properties, e.g. max. hygroscopicity, or elasticity indices are typical for sands or loamy sands [16].

The soil texture is the most stable feature, which practically does not change in the reclaimed land. The only exception from that rule is the covering of the surface with a layer of formations of different composition, which have more favourable properties.

2.2. Reaction

Reaction is one of the most important chemical features of soil. It is determined by the active acidity or the potential acidity (exchangeable and hydrolytic acidity). The value of the reaction, in case of mature soil, is influenced mainly by the climate and biocenosis. In Polish conditions, i.e. the humid zone, soil acidification is a natural process, resulting from leaching alkali elements from the outer layers of soil. Soils of neutral or alkali reaction occur only where the parent material contained a great amount of alkali components (mainly calcium carbonate). Such reaction may also be typical for arable soil, fertilized with alkali fertilisers, and for soil in the areas contaminated with dust containing Ca and Mg compounds. Anthropogenic acidification of soil, occurs, in turn, in the areas of acidifying emission (e.g. SO_x and NO_x), and in areas of intense agricultural and forestry activity supplying physiologically acid fertilizers to the soil, and removing alkali elements with the crops.

In case of the initial soil, present in the reclaimed areas, the reaction depends mainly on the features of the formations –parent material and the nature and speed of processes present there. Weathering of formations from other geochemical zone, especially when they contain sulphites (overburden and barren rock) may lead to a noticeable change of the reaction, e.g. acidification. Therefore, the reaction alone, determined for the formations present in the overburden or in the dump area, is not sufficient to draw conclusions as to the conditions for growth of plants during the reclamation. In order to better depict the situation, tests may be carried out which will allow the buffering substances and the scope of possible changes of reaction to be evaluated, and to decide on possible remedies afterwards.

2.3. Availability of Basic Nutrients (P, K, Mg)

The knowledge of the contents of soluble formations of basic nutrients determines the needs for fertilizers, which is important in assessing the overall reclamation cost. However, this assessment is not enough, as the possible shortages in fertilizers are relatively easy to make up for. Moreover, the limits of "available elements" adopted in the Egner-Riehm or Schachtschabel methods, sometimes fail to reflect the actual availability of nutrients in case of "raw" soil. For example, the richness of available phosphor forms is often low, yet the plants do not show symptoms of its shortage [10, 13]. In case of "raw" soil, the plants can use perhaps nutrients from even less soluble compositions. The problem of low estimation of the richness may sometimes be "omitted" by using other extraction methods, for example Domingo method [9].

3. Evaluation of Reclaimed Dump Areas of Sulphur Strip Mine

In Poland, mineral "raw" materials are often mined with the pit method, which involves the formation of overlay dumps. Almost every mine has an external dump area located nearby. Such areas vary in size and shape (height, land shaping, including bank slope etc) and the type of accumulated formations. The above features further influence the possibilities, problems, effects and methods of land reclamation.

The employees of the Department of Management and Protection of Environment AGH since the 1960-ties participated in the reclamation activities in almost all larger dumps of brown coal and sulphur mines. The documentation gathered allows to perform comparison of the features and properties of formations present in the reclaimed areas, which can be regarded representative for a vast part of the dumps. This forms the grounds which allow to determine the evaluation criteria. The information gathered on the progress and results of the reclamation make it also possible to verify the assessment.

3.1. External Dump of Piaseczno Sulphur Mine

The external dump of the sulphur mine of Piaseczno is situated in the Sandomierska Valley within the left-side terrace of the Vistula river. It is composed of the quaternary and tertiary formations which, as a result of non-selective dumping, were mixed and formed a sort of mosaic – occasional layers arrangement and mixture of sand and silt. Such mosaic structure is typical for the northern part of the dump, and the other parts represent relatively homogeneous formations – silt or sand.

The quaternary formations are the quartz sand with some addition of gravel. Aside from the predominating quartz, in those formations there are some slight amounts of potassium and sodium and calcium feldspar (plagioclases) and silt minerals (mainly the chlorites and montmorillonites) [1, 3, 4].

The tertiary formations are composed of the Krakowiec clays in which small gypsum and pyrite crystals and shell detritus are met. The clays are composed of montmorillonite and silt, and – in the larger fraction occurring occasionally – of quartz, glauconite, oxides and ferro-hydroxides. The dump is characterised by a varied shape, its fragments are strongly cut by water erosion [11].

The dump area has been reclaimed for forestry purposes. The coverage is non-uniform all over the area. Parts of compact forest stand and parts in which the seedings were lost can be distinguished. This perhaps, in most cases, was due to the negative properties of soil.

The dump of the Mine of Piaseczno has already been subject of repeated studies carried out both in the centre of Krakow [5, 15] and of Lublin [19, 20]. In the recent years, Bykov [1] has drawn up a detailed paper on the properties of soils. Sampling was made on a regular mesh of 100 m side length. Based on the results obtained, and the data gathered previously, the characteristics of the basic dump soil properties can be given.

Soil Texture

While attempting to evaluate the reclaimed soil, in terms of the soil texture, it is necessary to decide on the classification criteria to be adopted.

In the Polish conditions, at least three variants can be considered:

1) division according to PN-86/B-02480, used by the building industry and engineering geology;
2) division stipulated in BN-78/9180-11, used for soil studies, according to which the soil and cartographic documentation in Poland was drawn up;
3) division adapted by PTGleb, recommended by PN-R-04033, valid from 1998.

The most reasonable division to be adopted is that based on the contents of particles <0,02 mm, to which the system of soil bonitation in Poland refers to division 2). However, in case of reclaimed "raw" soils, the dependency between the <0.002 fraction and features of the soil becomes more visible than that between the <0.02 fraction. Therefore, has been decided to discuss the properties, by classifying the soil in the formation categories: "coarse" containing 0–10%, "medium" 11–30% and "fine" > 31% < 0.002 mm fraction. As for the formations being characterised, there are also data related to the < 0.02 fraction, it will be possible to seek analogy in a bonitation series of Polish mature soils.

Figure 1 and table 1 (on the interleaf) refer to Piaseczno dump soils. The division of soil texture into coarse, and fine formation becomes visible. Fine formation covers the majority of the dump area. Medium formations created, in most cases, as a result of mixing the coarse and fine formations, are represented by a smaller group of samples. Such formations create small, usually irregular and incidentally spaced "islands" among the fine formations.

Low contents of the 0.05–0.002 mm fraction is typical for the "coarse" formation. Such formations also contain little 0.1–0.02 mm particles. The "fine" formations are mostly the clays, containing relatively much 0.05–0.002 mm fraction (19–57%). In most cases those are particles of 0.02–0.002 mm in size. Various soil texture in individual fragments of the dump area, create significantly different habitat conditions.

Specific and Bulk Density, Porosity

The specific density (Tabs 1 and 2 on the interleaf) of the "fine" products forming the dump is considerably higher than the density of the "coarse" formations. This is probably due to the presence of the calcite and other minerals of relatively high density in the clay formations.

Table 1. Basic properties of the soil in Piaseczno dump

Feature		Units	Coarse soils			Medium soils			Fine soils			Surface layer (top) (0–30 cm)			Deep layer (sub) (< 30 cm)		
			*N**	Mean	Std. Dev.	*N**	Mean	Std. Dev.	*N**	Mean	Std. Dev.	*N**	Mean	Std. Dev.	*N**	Mean	Std. Dev.
Content fractions Φ [mm]	1–0.1	%	204	89.63	5.80	88	47.36	20.94	322	14.84	7.99	369	44.423	33.546	245	44.245	37.910
	0.1–0.05	%	204	2.36	1.20	88	5.10	2.56	322	4.52	2.15	369	4.106	2.319	245	3.559	2.085
	0.05–0.02	%	204	1.51	1.51	88	6.40	5.56	322	5.84	2.58	369	5.084	3.954	245	3.576	2.812
	0.02–0.006	%	204	1.37	1.28	88	9.34	7.64	322	12.62	3.08	369	8.393	6.257	245	8.437	6.386
	0.006–0.002	%	204	1.29	1.54	88	10.72	6.58	322	18.457	3.89	369	11.545	8.234	245	11.796	9.282
	1–0.05	%	204	91.99	5.16	88	52.47	20.19	322	19.37	8.29	369	48.528	32.522	245	47.804	37.003
	0.05–0.002	%	204	4.17	2.89	88	26.45	16.51	322	36.92	5.62	369	25.022	16.228	245	23.808	17.264
	<0.002	%	204	3.86	2.72	88	21.08	6.17	322	43.74	6.38	369	26.450	17.621	245	28.433	20.796
Specific density		$g \cdot cm^{-1}$	160	2.62	0.05	73	2.60	0.1	262	2.68	0.09	312	2.622	0.081	185	2.689	0.203
Bulk density		$g \cdot cm^{-1}$	160	1.61	0.15	73	1.48	0.21	262	1.45	0.16	312	1.460	0.167	185	1.624	0.154
Porosity		%	160	38.76	5.26	73	43.28	6.9	262	44.27	5.27	312	44.362	5.888	185	38.742	5.241
L_y		%		n.o.		26	45.22	15.1	109	62.38	6.96	73	58.325	13.162	63	59.459	9.483
L_p		%		n.o.		26	25.72	9.2	109	30.85	5.77	73	31.070	8.358	63	28.236	4.388
W_p		%		n.o.		26	19.50	7.8	109	31.53	4.17	73	27.255	7.592	63	31.222	5.744
Max hygroscopy		%	27	1.46	0.95		n.o.		44	11.85	1.69	53	7.945	5.237	18	7.756	5.571
PPW			27	12.78	7.01		n.o.		44	45.04	5.81	53	32.124	15.254	18	34.694	21.632
Loss by dry combustion		%	160	1.58	1.65	73	6.02	5.12	262	5.31	3.35	312	5.532	4.063	183	1.959	1.323
MBC sorption		$cmol \cdot kg^{-1}$	131	3.00	2.75	40	24.39	11.96	179	35.41	7.29	193	23.726	16.706	157	19.937	16.200
pH in H_2O			204	6.74	1.1	88	7.30	0.8	322	7.45	0.18	369	7.190	0.791	245	7.197	0.807
pH in KCl			204	6.26	1.3	88	6.88	1.0	322	7.04	0.15	369	6.738	0.923	245	6.789	0.933
Electrical conductivity of water		$\mu S \cdot cm^{-1}$	160	140.5	2.73	73	573.3	646	262	1010.8	877	312	315.449	275.767	183	1260.820	1026.705
Content	$CaCO_3$	%	204	0.419	1.0	88	12.30	9.7	322	22.61	7.37	369	13.630	11.697	245	13.952	12.346
	available K_2O	mg/100 g	36	3.13	3.74	12	23.56	14.66	35	47.68	19.87	39	32.667	29.169	44	17.786	18.365
	available P_2O_5	mg/100 g	36	0.69	1.11	12	0.79	1.07	35	1.08	1.5	39	1.638	1.542	44	0.184	0.101
	overall P	%	87	0.008	0.007	23	0.03	0.01	103	0.035	0.009	124	0.026	0.016	89	0.021	0.016
	C	%	87	0.587	0.61	22	2.371	1.98	104	1.758	1.38	128	1.925	1.478	85	0.467	0.428
	N	%	87	0.050	0.05	17	0.180	0.17	85	0.163	0.13	112	0.162	0.136	77	0.041	0.030
C / N			87	13.001	7.71	17	12.013	8.23	85	10.597	3.72	112	12.004	3.810	77	11.580	8.876

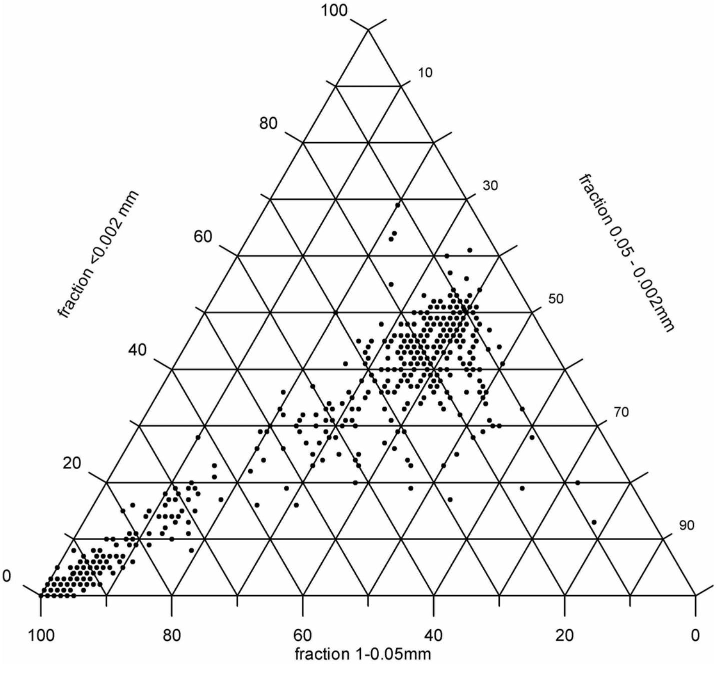
*N** – number of observations.

Table 2. Properties of Piaseczno dump soils in layer 0–30 cm (top) and layer > 30 cm (sub)

Feature		Units	Coarse soils (top)			Coarse soils (sub)			Medium soils (top)			Medium soils (sub)			Fine soils (top)			Fine soils (sub)		
			*N**	Mean	Std. Dev	*N**	Mean	Std. Dev	*N**	Mean	Std. Dev	*N**	Mean	Std. Dev	*N**	Mean	Std. Dev	*N**	Mean	Std. Dev
Content fraction Φ [mm]	1–0.05	%	116	90.578	5.010	88	93.852	4.762	67	55.284	19.912	21	53.476	21.503	186	21.000	8.454	135	16.911	7.101
	0.05–0.002	%	116	4.940	2.751	88	3.159	2.613	67	25.045	16.015	21	24.762	17.768	186	36.839	5.550	135	37.141	5.593
	<0.002	%	116	4.483	2.649	88	3.045	2.779	67	19.672	6.275	21	21.762	6.098	186	42.161	6.116	135	45.993	6.046
Specific density		$g \cdot cm^{-1}$	100	2.611	0.050	60	2.658	0.050	56	2.573	0.075	17	2.700	0.092	156	2.647	0.088	105	2.731	0.054
Bulk density		$g \cdot cm^{-1}$	100	1.540	0.138	60	1.727	0.080	56	1.434	0.179	17	1.677	0.174	156	1.422	0.162	105	1.603	0.084
Porosity		%	100	41.008	4.993	60	35.002	3.158	56	44.366	6.058	17	37.760	7.048	156	46.298	5.463	105	41.285	3.171
L_y		%							18	45.372	17.706	6	42.983	7.502	53	63.015	7.385	56	61.789	6.549
L_p		%							18	27.009	10.685	6	21.334	2.895	53	32.591	7.120	56	29.209	3.419
W_p		%							18	18.364	8.826	6	21.650	5.185	53	30.424	4.014	56	32.580	4.070
Max hygroscopy		%	21	1.733	0.891	6	0.483	0.160							32	12.022	1.481	12	11.392	2.165
Field capacity		%	21	14.995	6.388	6	5.050	0.731							32	43.366	5.897	12	49.517	1.990
Loss by dry combustion		%	100	2.294	1.733	60	0.402	0.255	56	6.848	5.058	17	1.999	0.975	156	6.993	3.382	105	2.853	0.815
MBC sorption		$cmol \cdot kg^{-1}$	68	3.908	3.072	63	2.028	1.961	32	23.745	12.995	9	20.517	11.622	94	37.470	6.612	85	33.150	7.379
pH w H_2O			116	6.638	1.103	88	6.885	1.166	67	7.325	0.701	21	7.190	1.075	186	7.484	0.190	135	7.396	0.149
pH w KCl			116	6.147	1.338	88	6.420	1.327	67	6.934	0.840	21	6.714	1.300	186	7.034	0.116	135	7.037	0.194
Electrical conductivity of water		$\mu S \cdot cm^{-1}$	100	136.500	143.537	60	147.167	407.361	56	353.571	294.195	17	1247.059	986.932	156	411.026	278.765	105	1909.524	672.695
Content	$CaCO_3$	%	116	0.456	0.921	88	0.370	1.126	67	10.725	8.813	21	14.098	12.226	186	22.526	7.377	135	22.873	7.210
	available K_2O	mg/100 g	12	3.942	4.414	24	2.725	3.392	9	24.956	15.425	3	19.367	13.975	18	56.106	24.119	17	38.771	7.540
	available P_2O_5	mg/100 g	12	1.667	1.519	24	0.196	0.108	9	1.000	1.167	3	0.167	0.153	18	1.939	1.694	17	0.171	0.085
	overall P	%	52	0.011	0.008	35	0.004	0.004	18	0.035	0.012	5	0.025	0.013	54	0.038	0.008	49	0.033	0.010
	C	%	52	0.894	0.630	35	0.131	0.096	17	2.8271	1.981	5	0.536	0.645	59	2.549	1.333	45	0.720	0.385
	N	%	52	0.075	0.057	35	0.012	0.008	13	0.2132	0.181	4	0.044	0.004	47	0.240	0.130	38	0.068	0.016
C / N			52	12.821	4.545	35	13.269	10.920	13	11.398	2.421	4	13.804	18.160	47	11.250	2.9948	38	9.790	4.358

*N** – number of observations.

a)



b)

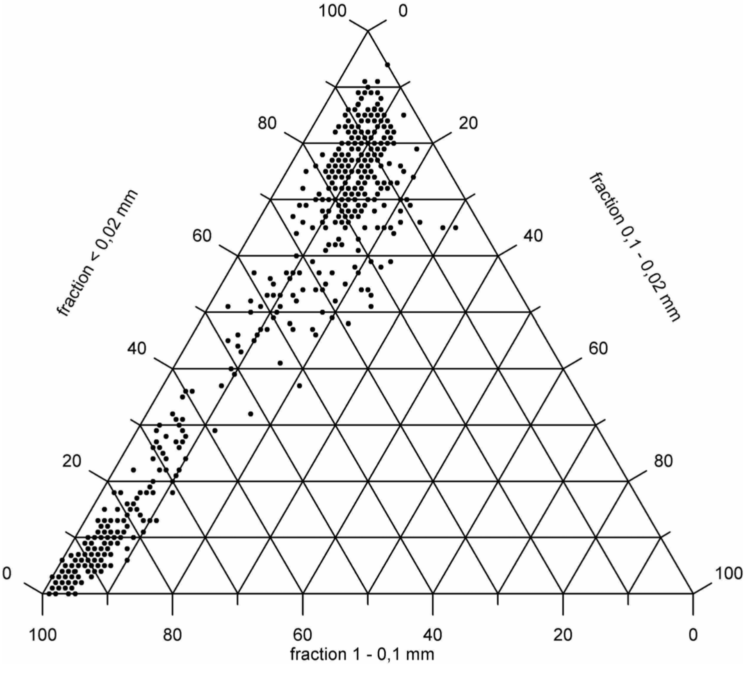


Fig. 1. Granular composition of Piaseczno dump soil acc. to:
a) PN-86/B-02480; b) BN 78/9180-11

The specific density of formations present in the superficial layers, calculated as an average of all analysed samples, is considerably less than that of the deeper layers, not subjected to the soil-formation process, which do not contain humus. This dependency stands out also in the case of separately analysed "fine" and "coarse" formations (Tabs 1 and 2).

This can be easily explained, as the addition of 1% humus of the density of 0.8 $g \cdot cm^{-3}$ reduces the density by 0.01–0.02 $g \cdot cm^{-3}$.

The bulk density of the "coarse" formations is higher than in the case of "medium" and "fine" formations.

The superficial layers are characterised by lower bulk density than the formations in the deeper layers of the profile. Considerable differences are present in the case of "fine" and "coarse" formations. The differences are shown in detail in figures 2–4.

The porosity in the superficial formations is considerably higher than in the deeper layers of the profile. This is particularly important for the "fine" formations, which, when loosened, significantly improve the conditions for growth of the plant roots.

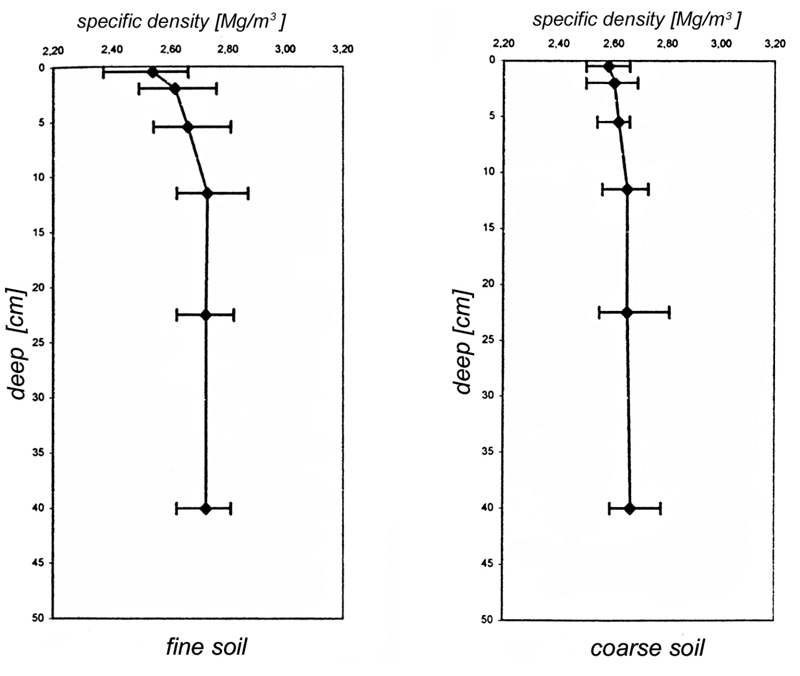


Fig. 2. Average vertical distribution of specific density of soils in Piaseczno dump

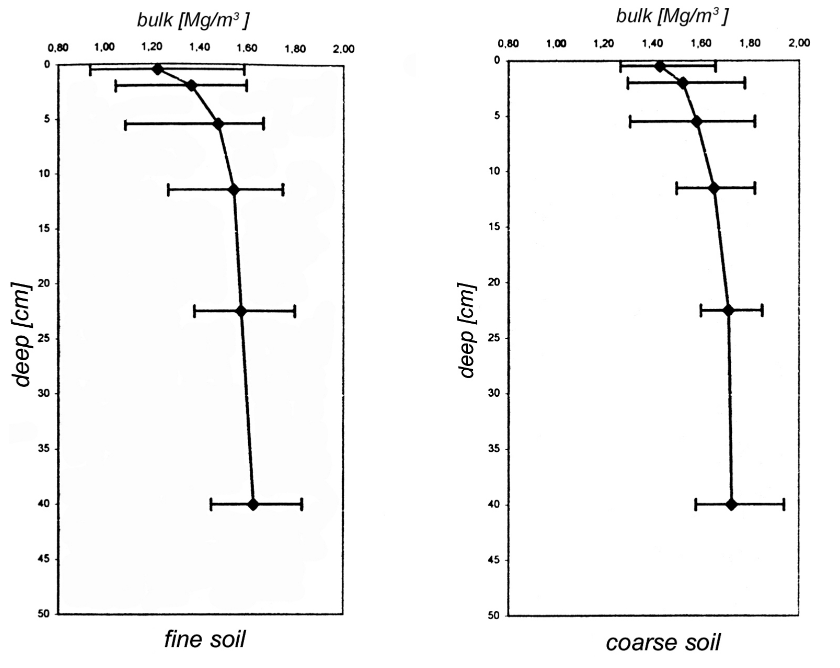


Fig. 3. Average vertical distribution of bulk density of soils in Piaseczno dump

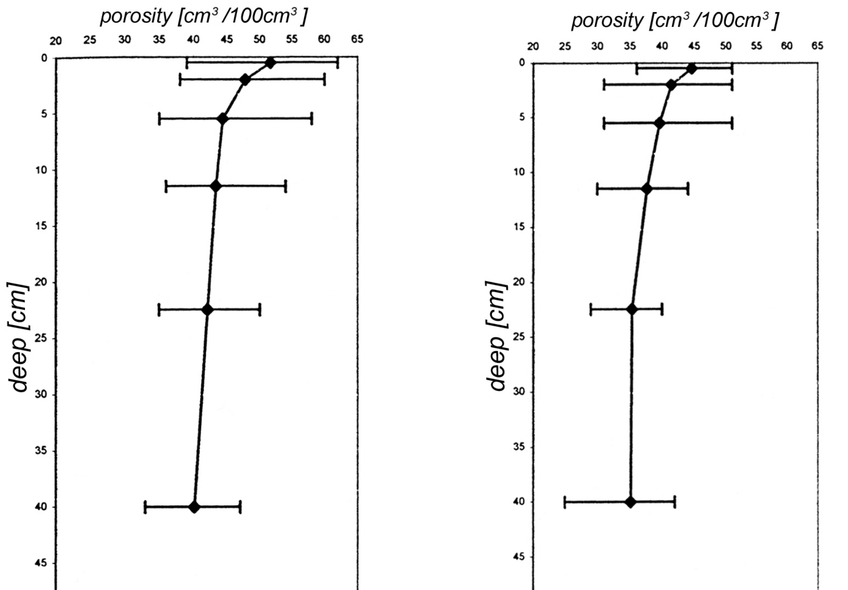


Fig. 4. Average vertical distribution of overall porosity of soils in Piaseczno dump

Water and Air Properties

The retention capability of formations can be evaluated by the analysis of co called water sorption curve (Fig. 5). It can be constructed based on laboratory tests or calculated from formulas developed by van Genuchten [18]. The results of the calculations of the retention capabilities of the formations present in the dump of Piaseczno are given in table 3.

The values given acknowledge the variability of water contents which is easy or difficult to access by the plants, in case of soils of various granularity, and the positive effects of the soil-formation process on the water and air conditions. In view of the results, the "medium" formations perform best. The contents of water which is easy or difficult to access is relatively highest, both in the superficial layers enriched with organic matter, and in the deeper layers as well. The "fine" formations are characterised by a very low number of macropores. This is especially true for the deeper layers. Despite some loosening resulting from the soil-forming process initiated, the surface levels contain still too little air pores. The amount of water available to plants is lower than that in case of the "medium" formation, whereby much of that water (around 50%) is hardly accessible (the share of water in the "medium" formations is a little lower – approx. 45%). In the "coarse" formations, the amount of water available to plants is lower than in the more cohesive ones. This applies particularly to the water of low availability to plants. The presence of organic matter affects the increase of water retention, and the share of the largest pores remains unchanged.

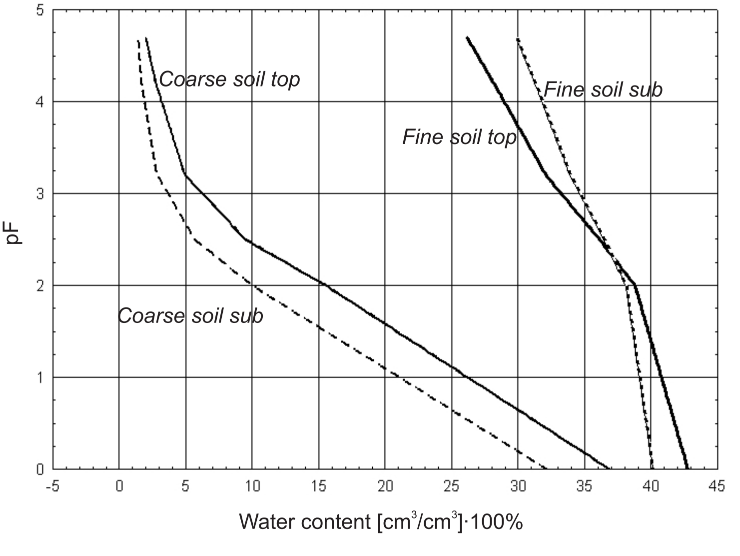


Fig. 5. Water sorption curves (pF curves) of the surface layer of reclaimed soils of Piaseczno dump

Table 3. Water retention of Piaseczno dump soil, calculated acc. to van Genuchten formulas

Soils	Sampling depth [cm]	Number of observations	pF	Water [cm³/cm³] · 100%			
				Mean	Stand. Dev.	Min	Max
Fine	0–30	185	0–2.5	6.63	2.60	2.17	14.60
			2.5–3.2	4.04	0.97	2.11	7.17
			3.2–4.2	3.94	0.76	4.46	13.64
	>30	135	0–2.5	3.69	1.11	1.13	6.70
			2.5–3.2	2.55	0.52	1.14	3.94
			3.2–4.2	2.63	0.46	1.13	3.93
Medium	0–30	63	0–2.5	12.56	0.40	4.77	22.58
			2.5–3.2	5.51	0.76	4.24	8.88
			3.2–4.2	4.66	0.84	2.98	6.76
	>30	22	0–2.5	12.11	4.69	3.31	20.81
			2.5–3.2	4.66	1.17	2.71	7.42
			3.2–4.2	3.88	1.03	2.70	6.03
Coarse	0–30	115	0–2.5	27.42	3.31	18.32	34.59
			2.5–3.2	4.50	1.41	2.00	7.50
			3.2–4.2	2.20	1.19	0.50	5.40
	>30	87	0–2.5	26.52	3.41	16.26	37.01
			2.5–3.2	2.79	0.84	1.49	5.52
			3.2–4.2	1.15	0.67	3.44	3.55

Changes in the formations, resulting from the soil-formation processes are also documented by e.g. the examination of the maximum hygroscopicity (Tab. 2). For the surface layers, it is higher than for the deeper ones, whereby in case of the "coarse" formation, such differences are significant.

The results of calculations of the retention capability differ from the data obtained during the laboratory tests (Tab. 4) [1]. This applies to both, the "fine" and "coarse" formations. In the first case, the amount of macropores assayed in laboratory tests is much higher (1.7 times higher in the surface layers and 2.7 times in the deeper layers) than the calculated one. Also, the share of mezopores, which are crucial for the amount of water available to plants, according to laboratory tests, is higher, but still higher in the parent material level than in the surface layer enriched with organic matter.

Table 4. Average share of groups of pore in overall porosity of the soils in Piaseczno dump

Soils	Sampling depth [cm]	Pore groups	Share acc. to calculations [%]	Share acc. to laboratory test [%]
Fine	0–30	macropores	15.5	28.5
		mezopores	18.6	17.9
		micropores	65.9	53.6
	>30	macropores	9.2	25.4
		mezopores	12.9	21.9
		micropores	77.9	52.7
Medium	0–30	macropores	30.4	
		mezopores	24.7	
		micropores	44.9	
	>30	macropores	33.7	
		mezopores	23.8	
		micropores	42.5	
Coarse	0–30	macropores	74.2	66.1
		mezopores	18.2	14.3
		micropores	7.6	19.6
	>30	macropores	82.6	86.8
		mezopores	12.1	5.7
		micropores	5.3	7.5

The soil-formation process initiated in the "fine" formations, in view of those findings, results in an improvement of the aeration conditions only. In case of the "coarse" formations, the amount of water determined by the laboratory tests, especially that readily accessible to plants, in the surface layer, is apparently higher, and lower in the deeper layers. This could also prove the reduction of defects in those formations (too high permeability) during the biological reclamation.

The differences in determination of the retention capability, in case of the calculated and laboratory tested values, can be, to some degree, explained by the difference in the number of samples taken into consideration. The laboratory tests appear to indicate too high share of macropores in case of the "fine" formations from the deeper layers. This may be due to the determining technique alone, when the soil paste is formed which is loosened in comparison with the mature soil structure.

Consistency Limits

The properties of cohesive soils depend strongly on their humidity. The sensitivity to changing the amount of water in the soil can be described by giving the limits of consistency and of the elasticity index (Tabs 1 and 2). In case of the "fine" formations from the dump of Piaseczno, the values of both limits are high. The "medium" formations are characterised by apparently lower L_y and L_p values. Standard deviation of the limits being determined is, in the case of the "medium" formations, significantly higher than that for the "fine" ones. This is mainly attributable to the smaller size of the set, but also to a greater variability of the granular composition of the "medium" formations, resulting from mixing the soil during exploitation and dumping, in accidental proportions.

The study of the correlations (Tab. 5) proves an important dependency between the fluidity and elasticity limits, elasticity index, and the amount of particles $\Phi < 0.02$ mm and $\Phi < 0.002$ mm.

Also the correlation coefficients between the L_y, L_p and the organic matter content are significant, as determined both, as the roasting loss and with the Tiurin method. Also, the increase of sorption capability (MBC sorption) is linked with the increase of L_y, L_p and W_p. The results indicate that the L_y value largely depends upon the fraction contents <0.02 and <0.002 mm, whereas the L_p value more considerably affects the organic matter contents. Similar dependences were discovered by Gołda [6, 7] by analysing changes taking place in the reclaimed postflotation sludge. The presence of $CaCO_3$ has some influence on the physical properties determined by testing the consistency limits. Such dependencies are most apparent while looking at the entire set of samples of various granulation, whereby in case of sets of the "fine" and "medium" samples from the surface and deeper layers, discussed separately, the correlation coefficients are different. Attention is drawn to the lack of correlation between the L_y, L_p and W_p values, and the contents of the finest particles, in case of the "fine" formations from the surface layers in case of strong links with the sorption capability and organic matter contents.

In case of formations from the deeper layers, not subjected to the soil-formation processes, the dependency between the consistency limits and the finest fraction contents is significant, however, there are no links with loss by dry combustion. The results for the "medium" formations are less reliable due to a smaller count of the set.

According to the tests of consistency limits of the surface and deeper layer samples, the "raw" "fine" formations are characterised by excessive cohesiveness. As a result of soil-formation processes initiated by the reclamation, especially the organic matter accumulation, the Wp has lower values. Such change, reflecting the reduction of cohesiveness, improves the cultivation properties, improves roots penetration etc.

Table 5. Selected correlations between the properties of Piaseczno dump soils (only significant correlations are provided at $p < 0.5$)

	Content fraction		Loss by dry combustion	MBC sorption	Content $CaCO_3$	Content C
	<0.02 mm	<0.002 mm				
Overall samples set (all soils)						
*N**	136	136	60	136	136	54
L_y	0.70	0.72	0.45	0.65	0.21	0.57
L_p	0.36	0.38	0.82	0.45		0.85
W_p	0.79	0.81	–0.37	0.62	0.37	
Fine soils (top and sub layer)						
*N**	109	109	49	109	109	43
L_y	0.39	0.45	0.56	0.34	–0.39	0.72
L_p			0.87	0.25	–0.36	0.90
W_p	0.54	0.63	–0.36	0.23		
Fine soils (sampling depth 0–30 cm "top")						
*N**	53	53	23	53	53	23
L_y			0.74	0.46	–0.36	0.84
L_p			0.91		–0.43	0.91
W_p				0.40		
Fine soils (sampling depth > 30 cm "sub")						
*N**	56	56	26	56	56	20
L_y	0.76	0.61			–0.43	
L_p	0.67	0.50			–0.36	
W_p	0.65	0.56		0.34	–0.38	
Medium soils (top and sub layer)						
*N**	26	26	11	25	26	11
L_y	0.46	0.75	0.96	0.79	0.46	0.92
L_p		0.57	0.97	0.56		0.94
W_p	0.55	0.77		0.87	0.70	
Coarse soils (top and sub layer)						
*N**	131	131	87		131	75
MBC sorption	0.75	0.65	0.86		0.41	0.75
*N**	27	27	27	14	27	17
Max higroscopy	0.76	0.76	0.88	0.72	0.62	0.82

*N** – number of observations.

Reaction, $CaCO_3$ Contents

The reaction of majority of samples collected from the dump of Piaseczno is between slight acid to neutral, whereby the “fine” formations have higher pH values than those of the “coarse” and “medium” ones (Tabs 1 and 2). In all samples of the “fine” formations $CaCO_3$ is present. This compound occurs also in some samples of the “medium” and “coarse” formations. There is apparently a weak link between the reaction and $CaCO_3$ contents, but the study revealed weak or no correlations. The dependency may be characterised as follows: presence of $CaCO_3$ decides on the pH to be less than 6.5. Greater amount of $CaCO_3$ causes usually the increase of pH, however, the pH values for the same $CaCO_3$ contents may vary (from 6.5 to 7.5), or, to one pH value various $CaCO_3$ values can apply. While evaluating the dump soil in terms of the above, it has to be stressed that the conditions are proper due to the lack of acidification of “raw” dump soil and the presence of carbonate buffer. At the same time, some slight reduction of calcium carbonate contents in the surface layers in relation to the deeper layers is noticeable. The differences are not significant, but may confirm the process of decalcification of the formations, as indicated by various studies, in the layer of initial soil formation process.

The carbonates, present in the dump soil, contribute somewhat to the improvement of their structure. While looking at the entire set of samples from the dump, in case of the deeper layers, the $CaCO_3$ contents is seriously (R = 0.61 for 183 samples) correlated with the porosity. For the set of “fine” formations discussed separately, however, that dependency practically does not exist. In case of the “coarse” formations, it is hard to find such dependency, since only minority of them contain carbonates. Admixture of carbonate clays to sand formations, however, as this is the case of the “medium” formations, considerably affects the increase of porosity. However, due to a low count of that set, no far-reaching conclusions should be drawn.

Sorption

One of the methods allowing to characterise the sorption properties of the soil, is to determine so called sorption of methylene blue (MBC), depending on the surface of the solid phase. In case of the formations of the dump of Piaseczno, the values vary considerably from 0.2 to 55.3 $cmol^{(+)}/kg$, according to variability of the clay fraction. The dependency, discussed separately for the “fine” and “coarse” formations varies. For the “fine” formations, the correlations between the <0.002 mm fraction and the sorption is negligent, both in case of the formations from the surface and from the deeper layers. In the group of “coarse” formations, however, the dependency between the fine particles and MBC is important. The effect of the 0.02–0.002 mm fraction on the increase of sorption is typical.

Sorption in the surface layers is considerably higher than in the deeper ones. This is related to the presence of organic matter, strongly correlated with the sorption, in all groups of formations. (Tab. 5, Fig. 6).

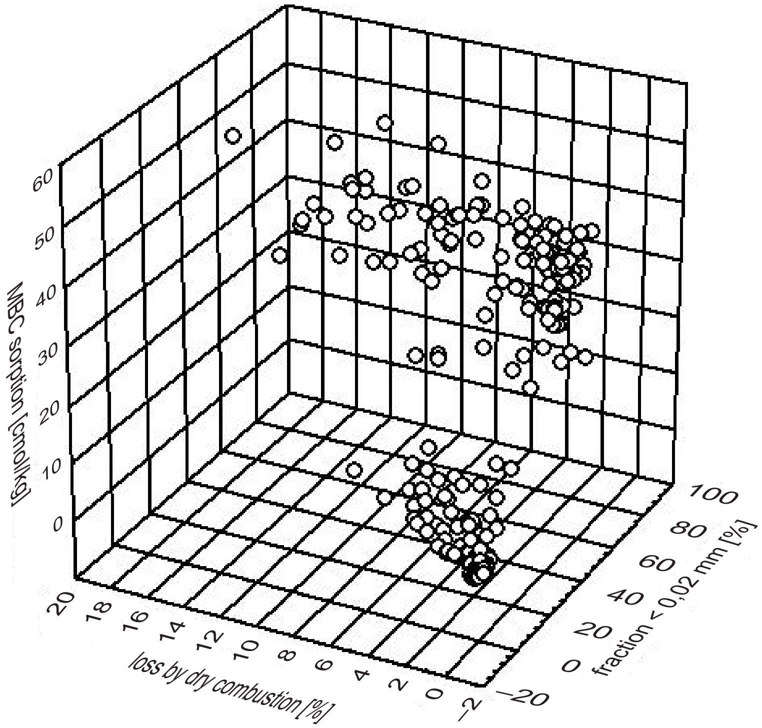


Fig. 6. Graph of BM sorption values spread in relation to the <0.02 mm fraction and loss by dry combustion contents

P, K, Mg Contents

The soil of the dump of Piaseczno is characterised by varied overall contents of absorbed nutrient compositions, related to the variability of granular composition (Tabs 1 and 2). This applies particularly to the potassium compounds. "Coarse" formations contain little potassium, in the "medium" formations, the contents of absorbed potassium forms is medium or high, whereas all "fine" formations have the medium or high potassium contents.

The contents of absorbed phosphor forms in all analysed samples is low. The overall contents of this element is also low. In the samples tested, only the overall magnesium contents was determined. Similarly to the overall potassium contents, it is also closely related to the granular composition of samples. Potassium contents are close to those reported for the mature soil of similar composition.

In case of all groups of formations, the contents of nutrients is higher in the surface layers enriched by the organic matter.

4. Summary of Results

The test results presented herein allow to assess the productivity of the dump soil of the Sulphur Mine of Piaseczno. Closer attention is required to the physical properties of such formations which, in many cases, are deciding for the success of the reclamation [14].

4.1. Dump Formations as a Potential Substrate for Vegetation

Based on the results gathered, it can be stated that the soil accumulated in the dump of Piaseczno, in most cases, is a good substrate for the growth of plants.

The first applies in particular to the formations classified as the "medium", and is related mainly to their favourable physical properties. In this group of formations, the air porosity is relatively high, and there is good capability for the retention of water which is mainly available to plants. Their cohesion (W_p 16–23%) is not sufficiently high to pose a considerable risk for the mechanical cultivation. The sorption guarantee good usage of the fertilisers utilised. The reaction varies from acid to basic, whereby a vast part of such formations contains carbonates, which should prevent the acidification trends.

The "fine" formations are characterised by much worse physical properties. A very high contents of the <0.002 mm fraction increases their cohesiveness which, in turn, hinders the mechanical cultivation. Another drawback of those formations are the water and air conditions. The porosity is relatively high, but its structure is improper – air porosity is very low (only around 4% in the layers not subjected to the soil formation process), also the volume of pores which are critical for the retention of water available to plants is low (around 5%). Such formations are characterised by good sorption which is reflected by the MBC. Reaction of those formations is neutral to basic, and they contain from several to several dozen percent of $CaCO_3$.

The third group, i.e. the "coarse" formations have a considerable share of large, air pores, and low retention capability for water to be used by plants.

The availability of nutrients in case of the "coarse" and "medium" formations is great enough to ensure the needs of plants to be satisfied. In fact, the availability of absorbed phosphor forms is low, yet the findings on the reclaimed areas of both, the dump in question and other areas, indicate no phosphor shortage symptoms of the plants. Also, the chemical composition of plants analysed does not differ from the average values. In the "raw" soil and initial stages of soil development, the plants are perhaps able to use more intensely the nutrients which are difficult to absorb. The "coarse" formations are not a suitable substrate for more demanding plants, and their low sorption capability may impede the rational use of the utilised fertilisers.

4.2. Soil Evaluation According to the Existing Classification of the Physical Properties

An important problem while developing the methods for the evaluation of reclamation soil is to determine which physical and chemical properties of such formations affect their productivity the most.

One of the first classifications of the quality of soil to be reclaimed, based on the results of laboratory test, was developed by professor Tadeusz Skawina. The method distinguishes four classes of potentially productive soil (A, B, C, D) and the toxic soil class divided into the EC and ED subclasses. Potentially productive formations and non-productive formations are properly classified based on the points scored – so called bonitation number LB (from 0 to 100), which is a sum of the lithological, calcium, cohesiveness and sorption indices [15].

The formation being evaluated is assigned to an appropriate bonitation class, according to the following criteria:

Class A	LB > 75 points
Class B	50 < LB < 75 points
Class C	21 < LB < 50 points
Class D	LB < 21 points

In this paper, a different method for evaluation of the soil quality is proposed, which refers first of all to the retention capability, related to the grains structure, porosity and sorption capability characterised by the physical sorption [2, 8, 17].

The value of the "x" soil assessment index, from 1 to 10, is obtained by the multiplicative method. The following can be distinguished:

1. formations of very high soil formation activity, scoring 8.0–10 points;
2. formations of soil-formation activity, easy to be biologically adopted, scoring 6.0–7.9 points;
3. formations of relatively high soil-formation activity, but hard to be biologically adopted, scoring 4.0–5.9 points;
4. formations of very low soil formation activity, scoring 2–3.9 points;
5. formations of very bad soil-formation properties, scoring below 2 points.

Using the methods described above, the soil of the dump of Piaseczno has already been evaluated. The average results are given in table 6.

Table 6. Evaluation of the feasibility of Piaseczno dump for reclamation

Soils Sampling depth [cm]		LB (Bonitation Number)					Number "X"				
		Number of observ.	Mean	Min	Max	Stand. Dev.	Number of observ.	Mean	Min	Max	Stand. Dev.
Fine soils	0–30	53	61.217	51	70	3.5267	53	6.7496	5.26	7.85	0.4530
	>30	56	60.696	50	70	4.5082	56	6.1579	3.724	7.9	0.7579
Medium soils	0–30	18	62.8056	20	96	16.4952	32	7.3494	4.656	8.7	1.0730
	>30	6	63.833	48	82	13.1327	9	6.717	5.071	7.85	0.9682
Coarse soils	0–30	71	12.1268	0	51.5	9.297	70	5.117	1.748	8.364	1.8228
	>30	63	6.7698	0	32.5	6.407	59	3.8703	1.4703	7.5245	1.5948

The LB values obtained require the soil of Piaseczno dump to be classified, both the "medium" and "fine" formations, as the B class (good quality soil), and the "coarse" formations, to the D class (non-productive soil). In case of the "fine" soil, the LB of samples collected from the surface layer is higher than that calculated for the samples from the deeper layers, not affected by the soil-formation process. The increase of the LB, however, does not create grounds to give a better mark to the soil and, moreover, the difference is not significant. In case of the "medium" soil, the LB values differ significantly which, in addition to a small count of the set, does not allow conclusions to be drawn as to the effects of reclamation on the change of quality. The "coarse" soil, from the surface layer, is characterised by considerably higher LB, yet, it is still considered to be non-productive.

In case of the evaluation based on the "X" value, the "fine" soil from the deeper layers, which representative the before- reclamation formations, can be classified as 3 or 2 groups – formations. Soil from the surface layer, affected by the soil-formation process, are ranked high enough to be classified in a higher category, whereby the difference is quite significant. The "medium" soil can be classified in the category of active formation, yet, apparent increase of the index for the surface layer is striking, however, due to a small number of tries, this difference is not significant. The "coarse" soil from the deeper layers is represented by formations of very low soil formation activity, yet for the surface layers enriched with the organic matter, there is an apparent improvement, which allows this soil to be classified as relatively active. With such results, it is possible to predict that the dump areas, on which the „medium" formations occur, may achieve productivity representing the IVa bonitation class, the "fine" formations – class C or IVb, and the "coarse" formations – class VI or V.

5. Conclusions

Results of these studies allow to formulate following conclusions:

1. Studies of reclaimed soil which examine only chemical properties do not give enough information about quality of the examined soil. Therefore it is necessary to enhance this study by including physical properties of the soil.
2. Among the area of Piaseczno dump the best properties for the plants were found in the "medium" formations. The "fine" and "coarse" soils represented unfavourable air and water properties.
3. After the initiation of the soil-formation processes all the soils show considerable improvement in their properties. Among changes which occur in the soil formation the number of mezopores and macropores increased. At the same time the cohesion of the "fine" soil decreases. This is a result of accumulation of organic matter.
4. The changes which are occurring during reclamation can be documented and monitored by appropriate measurement and observations. Therefore the applied reclamation method can he modified during the process.
5. Applied in this research Gruszczyński method, allows to take account of soil quality before and after reclamation.
6. Applied method allows classification of quality of soil and identifying, its class into appropriate soil bonification class as used in official classification of soil in Poland. In case of dump of Piaseczno reclaimed soil of "medium" formations can be identified as class IVa, "fine" as IVb or V, "coarse" class V or VI.
7. Applied method is based on uncomplicated analysis of physical properties of soil, and because of its easy-to-use method can be introduced into common use.

References

[1] Bykov R.: *Litologiczne i morfologiczne uwarunkowania procesów glebowych na terenie zrekultywowanego zwałowiska zewnętrznego Kopalni Siarki „Piaseczno"* (*Lithological and morphological conditions of soil processes on the premises of the reclaimed external dump area of the Sulphur Mine of Piaseczno*). AGH, Kraków 2003 (Ph.D. Thesis, typescript) (in Polish).

[2] Chwastek J., Żuławski C.: *Zagospodarowanie terenów przemysłowych* (*Utilisation of industrial area*). Liga Ochrony Przyrody, Warszawa 1981 (in Polish).

[3] Frankiewicz A., Pucek T.R.: *Hydrogeological and Hydrochemical Characteristics of the Partially Flooded Piaseczno Opencast Sulphur Mine in Southeastern Poland.* Mine Water and the Environment, No. 25, 2006, pp. 153–162.

[4] Fuk H., Gołda T., Trafas M.: *Badania utworów nadkładu i zwałowisk dla potrzeb rekultywacji na przykładzie górnictwa odkrywkowego siarki* (*Tests of the overlay and dump formations for the needs of reclamation, by the example of sulphur strip mining*). Zeszyty Naukowe AGH, Geodezja, nr 65, 1981, pp. 27–42 (in Polish, with an English summary).

[5] Gołda T.: *Dokumentacja kartograficzna terenów pogórniczych dla potrzeb rekultywacji i zagospodarowania* (*Cartographic documentation of post-mining areas for the needs of reclamation and land utilisation*). Kraków 1979 (Ph.D. Thesis, typescript).

[6] Gołda T., Gruszczyński S.: *Zmiany niektórych właściwości szlamów poflotacyjnych pod wpływem upraw rekultywacyjnych* (*Changes of some properties of post--floatation sludge as a result of reclamation*). Zeszyty Naukowe AGH, Sozologia i Sozotechnika, nr 36, 1991 (in Polish, with an English summary).

[7] Gołda T.: *Inicjalne procesy glebotwórcze zachodzące w szlamach poflotacyjnych w wyniku upraw rekultywacyjnych i wieloletniego użytkowania rolneo* (*Initial Soil Creating Processes Taking Place in Post-Flotation Slime in Result of Reclamation Cultivation and Long-term Agriculture Use*). Rozprawy Monografie, nr 164, UWND AGH, Kraków 2007 (in Polish, with an English summary).

[8] Gruszczyński S., Trafas M.: *Klasyfikacja poprzemysłowych obiektów bezglebowych dla celów rekultywacji* (*Classification of Post-mining Soilless Objects for Reclamation*). Inżynieria Środowiska, t. 6, z. 1, 2001, pp. 67–83 (in Polish, with an English summary).

[9] Kowalik S.: *Właściwości gleby inicjalnej, ukształtowanej w wyniku wieloletniej uprawy rolniczej gruntów zwałowiskowych górnictwa siarki* (*Propertied of initial soil formed as a result of prolonged agricultural use of dump soil from sulphur mining*). Zeszyty Problemowe Postępów Nauk Rolniczych, nr 418, cz. 2, 1995, pp. 709–716 (in Polish, with and English summary).

[10] Kowalik S.: *Problem fosforu w objętych rekultywacją rolniczą bardzo zwięzłych gruntach zwałowiskowych górnictwa siarki* (*The Problem of Phosphorus in the Agricultural Reclamation of Very Compact Grounds in the Heap of Sulphur Mining*). Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, nr 4, 1204, 2008, pp. 49–59 (in Polish, with and English summary).

[11] Krogulska E.: *Studium potencjalnego zagrożenia erozją wodną na zwałowisku zewnętrznym Kopalni Siarki Piaseczno* (*Study of the potential risk of water erosion in the external dump area of the Sulphur Mine of Piaseczno*). AGH, Kraków 2002 (M.Sc. Thesis, in Polish).

[12] Krzaklewski W.: *Fitosocjologiczna metoda oceny warunków rekultywacji na przykładzie skarp zwałowiska „Adamów"* (*The Phyto-sociological method of evaluating the conditions of reclaming and afforestation of waste land on example of dumping slopes of the "Adamów" colliery*). Archiwum Ochrony Środowiska, nr 3–4, 1979, pp. 121–165 (in Polish, with and English summary).

[13] Mocek A., Owczarzak W., Gilewska M., Rybczyński P.: *Wybrane właściwości fizyczno-chemiczne gleb wytworzonych na zwałowisku wewnętrznym odkrywki Pątnów pod monokulturą pszenicy i wpływem zróżnicowanych dawek nawożenia mineralnego* (*Selected physical and chemical properties of soils developed from an internal heap of the "Pątnów" opencast mine under long-term wheat monoculture and incluenced by varying doses of mineral fertilisers*). Annales UMCS, Sec. E, Vol. LIX, No. 4, 2004, pp. 1577–1585 (in Polish, with and English summary).

[14] Shukla M.K., Lal R., Ebinger M.: *Soil Quality Indicators for Reclaimed Minesoils in Southeastern Ohio*. Soil Science, Vol. 169, Issue 2, 2004, pp. 133–142.

[15] Skawina T., Trafas M.: *Zakres wykorzystania i sposób interpretacji wyników badań geologicznych dla potrzeb rekultywacji* (*Scope of utilisation and interpretation of geological study results for the needs of reclamation*). Ochrona Terenów Górniczych, nr 16, 1971, pp. 3–11 (in Polish, with and English summary).

[16] Trafas M., Eckes T.: *Glebotwórcze aspekty oceny utworów sztucznych na przykładzie pdpadów po flotacji rud cynku i ołowiu* (*Soil-making Aspects in the Evaluation of Artificial Formations; Focus on the Wastes Formed after the Flotation of zinc and Lead Ores*). Geomatics and Environmental Engineering, Vol. 1, No. 2, 2007, pp. 97–110 (in Polish, with an English summary).

[17] Trafas M., Gruszczyński S.: *Określenie relacji wskaźnika bonitacyjnego terenów bezglebowych do jednostek klasyfikacji gleb* (*The Definition of the Relationships of Bonitation Index for Soilless Areas to the Soil Classification Units*). Inżynieria Środowiska, t. 6, z. 1, 2001, pp. 161–169 (in Polish, with an English summary).

[18] Van Genuchten M.T.: *A Closed form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils*. Soil Science Society of America Journal, 44, 1980, pp. 892–898.

[19] Węgorek T.: *Zmiany niektórych właściwości materiału ziemnego i rozwój fitocenoz na zwałowisku zewnętrznym kopalni siarki w wyniku leśnej rekultywacji docelowej.* (*Changes of some properties of soil material and development of phytocenosis on the external dump of sulphur mine as a result of target forest reclamation*). Rozprawy Naukowe Akademii Rolniczej w Lublinie, Wydział Rolniczy, z. 275, Lublin 2003 (in Polish).

[20] Ziemnicki S., Węgorek T., Kowal W.: *Wstępne badania zmian niektórych właściwości materiału ziemnego zrekultywowanego zwałowiska kopalni siarki* (*Preliminary investigations on the changes of some properties of the soil material of the recultivated dump of sulphur mine*). Roczniki Gleboznawcze, t. XXXI, nr 3–4, 1980, pp. 211–218 (in Polish, with and English summary).