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PHYTOINDICATIVE EVALUATION OF HABITAT CONDITIONS OF SOILLESS FORMATIONS RECLAIMED WITH FLOTATION SLUDGE, SEWAGE SLUDGE AND USED MINERAL WOOL UNDER THE INFLUENCE OF THE JEZIÓRKO SULPHUR MINE*

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Abstract

The floristic observations presented below were carried out in 2011, on 5-acre plots delineated on an area of degraded soil. The soil-reclamation experiment, which began in June 2004, was set up on devastated soilless formation affected by the Jeziórko Sulfur Mine. In the experiment, the impact of different (200, 400, 800 m^3 ha^{-1}) doses of mineral wool and sewage sludge on characteristcis of the soilless formation was analyzed. The strongly acidic soilless formation (weak loamy sand) was reclaimed using flotation sludge in a dose of 100 t ha^{-1} for de-acidification, and various combinations of mineral wool and sewage sludge. The sward sown on plots pretreated as above consisted of a clover reclamation mixture with the following composition: *Festuca pratensis* – 41.2%, *Festuca rubra* – 19.2%, *Lolium perenne* – 14.7%, *Lolium multiflorum* – 12.4%, *Dactylis glomerata* – 6.5%, *Trifolium pratense* – 6%. A phytoindication method was employed to assess the impact of different reclamation methods of soilless formation on shaping the habitat conditions. This assessment took into account the following indicators: soil moisture, trophism, pH, organic matter content, resistance to salinity and to an increased content of heavy metals. The method for soilless formation reclamation was found to produce an effect on the analyzed ecological factors. The most favorable habitat conditions were recorded in soil reclaimed with mineral wool; they were worse in soil reclaimed with mineral wool and treated with NPK, but the worst parameters occurred in soil with the addition of sewage sludge and mineral wool.

Key words: ecological indicative numbers of vascular plants, reclamation, soilless formation, sulfur mine.

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INTRODUCTION

Borehole sulfur mining results in multiple transformations of the natural environment, particularly evident in soils due to the influx of chemically active minerals, poor native soil quality as well as the process of mining (Kołodziej, Słowińska-Jurkiewicz 2004, Lecyk, Brzezińska 2007, Gołda 2008). Native sulfur, sulfides and sulfur oxides emitted during the mining process are potential carriers of sulfuric acid into the soil, which inevitably leads to intense acidification and degradation, often devastation. These changes create a toxic environment for most crops, affected by an acute shortage of nutrients and increased mobility of phytotoxic elements (Motowicka-Terelak, Dudka 1991, Motowicka-Terelak 1993).

For the reclamation of degraded soils and their reconstruction on soilless formations near the Jeziórko Sulfur Mine, flotation sludge is successfully used for de-acidification, while adequate quality municipal sewage sludge is incorporated into soil to improve the resources of organic matter and nutrients (Baran et al. 2006, Krzywy et al. 2008).

Research on the application of used mineral wool for reclamation of devastated soils has been conducted for several years in that area. The results indicate strong influence of mineral wool on the formation of chemical, physicochemical and physical properties of reclaimed soils (Baran et al. 2008).

The plant cover is a reflection of inter-relationships and dependencies between the natural environment elements, especially the climate and soil properties. Changes in plant communities result from natural effects and anthropogenic factors, which vary in time and space (Roo-Zielińska 2004, Kalembasa, Malinowska 2009, Sądej, Namiotko 2010).

It is known that many plant species are good indicators of habitat conditions. Many years of research have led to the identification of specific association of many plant species with habitat factors, which is expressed in the form of ecological indicative numbers (Ellenberg et al. 1991, Zarzycki et al. 2002). This analysis may help to verify whether the technical and biological reclamation techniques implemented in degraded and devastated areas are adequate.

The aim of this study was to evaluate, using the phyto-indication method, the habitat conditions shaped on soilless formation reclaimed using flotation sludge, sewage sludge and used mineral wool from crops grown under cover, in an area under the impact of the Jeziórko Sulfur Mine.

MATERIAL AND METHODS

The study was carried out on experimental plots established in 2004 on some devastated area affected by the Jeziórko Sulfur Mine. For the reclamation of soilless formation, flotation sludge, municipal sewage sludge, used mineral wool Grodan and NPK fertilizers were applied. Strongly acidic soilless formation (weak loamy sand) was reclaimed using flotation sludge at 100 t ha^{-1} for de-acidification, and mineral wool or sewage sludge in various combinations. In the experiment, the impact of different (200, 400, 800 m^3 ha^{-1}) doses of mineral wool and sewage sludge on the features of soilless formation was analyzed. Grass with a clover reclamation mixture of the following composition: *Festuca pratensis* – 41.2%, *Festuca rubra* – 19.2%, *Lolium perenne* – 14.7%, *Lolium multiflorum* – 12.4%, *Dactylis glomerata* – 6.5%, *Trifolium pratense* – 6%, was sown on prepared plots

The paper contains results from the first year (2004) and several years afterwards (2011), in which phyto-sociological records were taken. Soil samples for laboratory analyses were collected each year in autumn.

The following analyses were performed on the collected samples: pH in 1 mol KCl dcm^{-3} by potentiometry, Corg. content by the Tiurin method modified by Simakov, Nog. by the Kjeldahl method. Eleven phyto-sociological records were taken by the method elaborated by Braun-Blaquet (1964) on plots reclaimed in the various ways. The habitat conditions were determined using indicative scores given by Zarzycki et al. (2002). The following indicators were taken into account: W – soil moisture content (1 – very dry, 2 – dry, 3 – fresh, 4 – moist, 5 – wet, 6 – water); Tr – trophism (1 – extremely poor soils, 2 – poor, 3 – moderately poor, 4 – abundant, 5 – very abundant); R – soil acidity (1 – strongly acidic soils, 2 – acidic, 3 – moderately acidic, 4 – neutral, 5 – alkaline); H – organic matter content (1 – soils poor in humus, 2 - mineral-humic soils, 3 – soils abundant in organic matter); S – resistance to NaCl presence in soil (1 – species tolerating increased NaCl content, 2 – species grown mainly on soils with increased NaCl content); M – resistance to increased heavy metals content in soil (1 – species tolerating increased content of heavy metals, 2 – species requiring increased concentrations of heavy metals).

RESULTS

In 2011, the pH value in the surface layer of the soilless formation reclaimed with different doses of used mineral wool and fertilized with NPK ranged from 5.2 to 6.0; in the formation reclaimed by sewage sludge, sewage sludge with mineral wool or mineral wool, the pH range was within 6.3-6.9. The reclamation method also influenced Corg. content. The highest average content of organic carbon was in the soil reclaimed with sludge, sewage sludge and mineral wool (12.3-23.2 g kg^{-1}); in the other reclamation variants, the Corg. content was similar (11.2-15.6 g kg^{-1}). The reclamation method had no effect on the total nitrogen content. However, the reclaimed soil was characterized by a higher content of total nitrogen (an average of 1.6 g kg^{-1}) than the control soil (1.1 g kg^{-1}) – Table 1.

Table 1

General properties of reclaimed soil

Reclamation variants	pH w KCl		Corg		Ntot.	
			(g kg^{-1})			
	2004	2011	2004	2011	2004	2011
NPK - control	6.9	6.4	9.5	8.9	0.4	1.1
Sewage sludge - control	7.3	6.8	5.7	14.2	0.9	1.4
Sewage sludge + mineral wool 200 m^3 ha^{-1}	7.2	6.9	8.6	23.2	1.2	2.4
Sewage sludge + mineral wool 400 m^3 ha^{-1}	7.2	6.7	10.6	13.6	1.2	1.3
Sewage sludge + mineral wool 800 m^3 ha^{-1}	7.1	6.8	9.7	12.3	1.0	1.4
Mineral wool 200 m^3 ha^{-1}	7.2	6.4	7.3	11.2	0.8	1.2
Mineral wool 400 m^3 ha^{-1}	7.1	6.3	12.1	15.2	1.4	1.6
Mineral wool 800 m^3 ha^{-1}	6.9	6.5	9.5	14.6	1.1	1.4
NPK + mineral wool 200 m^3 ha^{-1}	7.1	5.9	7.0	15.6	0.8	1.6
NPK + mineral wool 400 m^3 ha^{-1}	7.2	5.2	13.6	11.8	1.6	1.1
NPK + mineral wool 800 m^3 ha^{-1}	6.8	6.0	10.1	13.0	1.4	1.4

Seven years after the onset of the experiment, in addition to the plant species introduced as part of reclamation treatments, other plants were noted, which had entered the area by spontaneous succession over the analyzed soilless formation reclaimed with sewage sludge and varied mineral wool doses. The soils reclaimed with mineral wool were grown mainly by meadow species from the *Molinio-Arrhenathertea* class and by synanthropic and lawn species, as compared to other plots.

The range of humidity indicator ranged between 2 (dry habitat) to 6 (aquatic habitats). The analyzed area was dominated by species of fresh habitats (indicator 3), which accounted for 28.9% of the studied flora (Figure 1), with an average of 9 plant species (Table 2). Slightly less common (23.7%)

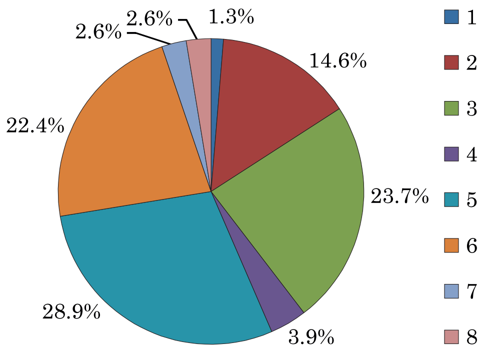

Fig. 1. Moisture content indicator:
1 – indicator 2; 2 – indicator 2-3; 3 – indicator 2-4;
4 – indicator 3; 5 – indicator 3-4; 6 - indicator 4;
7 – indicator 4-5; 8 – indicator 5-6

Table 2

Influence of reclamation method on the number of plant species according to the moisture content indicator

Reclamation variants	Moisture content indicator (W)							
	2*	2-3	2-4	3	3-4	4	4-5	5-6
NPK - control	7	8	2	9	9	2	.	1
Sewage sludge - control	4	3	1	9	2	.	.	.
Sewage sludge + mineral wool 200 m^3 ha^{-1}	1	4	2	8	2	.	1	1
Sewage sludge + mineral wool 400 m^3 ha^{-1}	1	5	1	6	3	.	.	.
Sewage sludge + mineral wool 800 m^3 ha^{-1}	.	7	1	8	3	.	.	1
Mineral wool 200 m^3 ha^{-1}	3	7	3	9	7	.	1	.
Mineral wool 400 m^3 ha^{-1}	3	7	3	11	10	.	.	.
Mineral wool 800 m^3 ha^{-1}	3	8	2	13	10	.	1.	.
NPK + mineral wool 200 m^3 ha^{-1}	3	6	3	10	8	.	.	.
NPK + mineral wool 400 m^3 ha^{-1}	2	8	3	9	6	1	.	.
NPK + mineral wool 800 m^3 ha^{-1}	1	8	2	12	6	1	.	.
Min.	1	3	1	6	2	1	1	1
Max.	7	8	3	13	10	2	1	1
Average	3	6	2	9	6	1	1	1
Coefficient of variation	64.8	27.2	39.8	20.8	51.6	-	-	-

* Key under Figure 1

were species with the indicator 2-3 (intermediate habitat between dry and fresh). A relatively high share was created by species with the indicator 3-4 (moist and fresh habitat), representing 22.4% of the analyzed vascular flora. Species with indicators 2 (dry habitat), 4 (moist habitats), and 5 (wet habitats), as well as 5-6 (wet and water habitats) represented much smaller shares: 14.6%, 2.6%, 1.3%, respectively. Over 3.9% of the total flora did not correspond to any specific moisture content indicator (range of indicators 2-4).

Our analysis of moisture indicators for the species present on the soilless formation reclaimed with the studied methods shows that the largest number of species of fresh (indicator 3) and intermediate between fresh and moist habitats (indicator 3-4) occurred on plots reclaimed using mineral wool, while fewer such plants were documented on soil reclaimed using wool with NPK (Table 2). The lowest number of such species was recorded after the application of sewage sludge and mineral wool.

The study shows that the soilless formation reclaimed with the tested methods was dominated by species of neutral habitats (indicator 4), which accounted for 39.6% of all the flora (Figure 2). Much fewer species were assigned indicators 2-3 (2.6%), 3 (6.6%), 3-4 (11.8%), 5 (2.6%), and 5-4 (15.8%). Species with a broad spectrum of adaptability to the acidity of substrate (species with indicators in the ranges 2-5 and 3-5) made up 14.5% of the total analyzed flora.

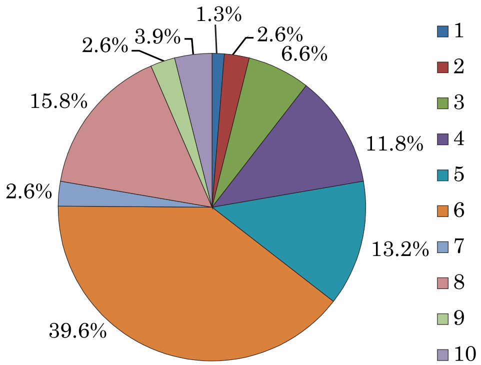

Fig. 2. The pH value indicator:
1 – indicator 2-3; 2 – indicator 3; 3 – indicator 3-4;
4 – indicator 3-5; 5 – indicator 4; 6 - indicator 2-4;
7 – indicator 4-5; 8 – indicator 5; 9 – indicator 4-5;
10 – indicator 2-5

Our analysis of individual reclamation variants indicates that the largest number of species with indicator 4 (neutral habitat) was present in the reclamation variant with mineral wool, fewer in the variant with mineral wool and NPK, and the fewest - with sewage sludge and mineral wool (Table 3). Regardless of the reclamation variant, the average number of species with indicator 4 was twelve, while those with indicator 4-5 were six on average. For these indicators, the variation coefficient was also the lowest.

Table 3

Influence of reclamation method on the number of plant species according to the acidity indicator

Reclamation variants	Acidity indicator (R)									
	2-3*	3	3-4	3-5	4	2-4	4-5	5	5-4	2-5
NPK - control	1	.	4	.	7	1	6	.	.	1
Sewage sludge - control	1	3	4	4	17	.	6	2	1	1
Sewage sludge + mineral wool 200 m^3 ha^{-1}	1	.	5	2	15	.	6	.	1	1
Sewage sludge + mineral wool 400 m^3 ha^{-1}	.	.	5	2	12	.	2	.	.	.
Sewage sludge + mineral wool 800 m^3 ha^{-1}	.	.	2	2	7	.	5	.	.	.
Mineral wool 200 m^3 ha^{-1}	.	1	2	5	15	.	5	.	1	1
Mineral wool 400 m^3 ha^{-1}	.	.	5	6	15	.	5	.	2	1
Mineral wool 800 m^3 ha^{-1}	.	.	4	6	17	1	6	.	2	1
NPK + mineral wool 200 m^3 ha^{-1}	.	.	3	6	11	1	7	.	1	1
NPK + mineral wool 400 m^3 ha^{-1}	1	1	3	5	10	.	6	.	2	1
NPK + mineral wool 800 m^3 ha^{-1}	1	1	3	4	11	1	7	.	1	.
Min.	1	1	2	2	7	1	2	2	1	1
Max.	1	3	5	6	17	1	7	2	2	1
Average	1	2	4	4	12	1	6	2	1	1
Coefficient of variation	-	66.7	30.8	40.2	29.0	-	24.7	-	37.6	-

* Key under Figure 1

Fertility of habitats was assessed according to the trophic indicator (Tr). The analysis of this indicator (Figure 3) reveals the presence of species with the full spectrum of trophic requirements within the examined vascular flora. Species with very low nutritional requirements (indicator 1-2), moderately poor habitat species (indicator 3), and abundant and fertile habitats species (indicator 4 and 5) alike grew on the studied soilless formation reclaimed with different methods. The results show the advantage of abundant habitat species, eutrophic ones (trophic indicator 4), representing 34.3%

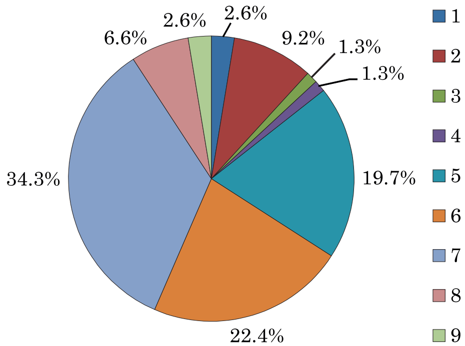

Fig. 3. Trophic indicator:
1 – indicator 1-2; 2 – indicator 2;
3 – indicator 2-3; 4 – indicator 2-4;
5 – indicator 3; 6 - indicator 3-4;
7 – indicator 4; 8 – indicator 4-5;
9 – indicator 4-3

of the total flora studied. The smallest share was made up by taxa with low trophic requirements (poor and moderately poor habitats - indicator 1-2 and 2), as well as habitats intermediate between abundant and very abundant.

Our analysis of trophic indicators for species grown on the soil reclaimed using the tested waste shows that the largest number of fertile habitats species (indicator 4) and intermediate between moderately poor and fertile ones (indicator 3-4) was found on plots reclaimed with mineral wool, fewer on soil reclaimed with wool + NPK, and the fewest on plots where sewage sludge as well as sewage sludge with mineral wool were applied (Table 4). The highest mean species abundance, regardless of the reclamation variant, was assigned to plants characterized by indicator 4 (10 species) and 3-4 (7 species).

The study carried out on reclaimed soilless formation indicates a significant advantage of species associated with mineral-humic soils (indicator 2). On average, they represent 76.3% (22 species) of the studied flora, regardless of the reclamation method. The contribution of species with indicator 1 (soils poor in humus) and 3 (soil abundant in organic matter) is much smaller:

Table 4

Influence of reclamation method on the number of plant species according to the trophic indicator

Reclamation variants	Trophic indicator (Tr)								
	1-2*	2	2-3	2-4	3	3-4	4	4-5	4-3
NPK - control	2	5	.	.	8	8	14	2	1
Sewage sludge - control	.	2	.	.	5	3	6	2	.
Sewage sludge + mineral wool 200 m^3 ha^{-1}	.	1	.	.	2	4	9	2	1
Sewage sludge + mineral wool 400 m^3 ha^{-1}	.	.	.	.	3	5	7	2	.
Sewage sludge + mineral wool 800 m^3 ha^{-1}	.	.	.	.	3	5	8	4	1
Mineral wool 200 m^3 ha^{-1}	1	1	.	1	5	8	10	3	1
Mineral wool 400 m^3 ha^{-1}	.	1	.	1	6	11	11	3	1
Mineral wool 800 m^3 ha^{-1}	.	2	.	.	5	10	16	3	1
NPK + mineral wool 200 m^3 ha^{-1}	.	1	.	1	5	9	10	3	1
NPK + mineral wool 400 m^3 ha^{-1}	.	2	.	1	5	10	9	2	.
NPK + mineral wool 800 m^3 ha^{-1}	.	.	1	.	6	8	11	2	1
Min.	1	1	1	1	2	3	6	2	1
Max.	2	5	1	1	8	11	16	4	1
Average	2	2	1	1	5	7	10	3	1
Coefficient of variation	47.1	72.3	-	-	34.5	36.6	28.9	27.0	-

* Key under Figure 1

2.6% and 5.3%, respectively. In some plots, the proportion of species with a broad spectrum of requirements in relation to the organic matter content (indicators 1-2 and 2-3) was apparent (Figure 4).

The analysis of the impact of different reclamation methods indicates that the largest number of species with indicator 2 (mineral-humic soils) was on the plots with mineral wool, fewer – on plots with mineral wool plus NPK, and the fewest – on plots with sewage sludge and mineral wool. On

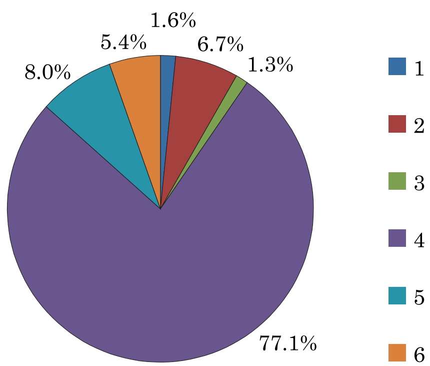

Fig. 4. Organic matter content indicator:
1 – indicator 1, 2 – indicator 1-2,
3 – indicator 1-3, 4 – indicator 2,
5 – indicator 2-3, 6 - indicator 3

the soil reclaimed using sewage sludge and mineral wool, noteworthy is the presence of species with a very wide spectrum in terms of the organic matter content demand (indicator 1-3) – Table 5.

Table 5

Influence of reclamation method on the number of plant species according to the organic matter content

Reclamation variants	Organic matter content indicator (H)					
	1*	1-2	1-3	2	2-3	3
NPK - control	.	2	1	15	.	1
Sewage sludge - control	1	5	.	28	3	3
Sewage sludge + mineral wool 200 m^3 ha^{-1}	.	.	1	22	4	3
Sewage sludge + mineral wool 400 m^3 ha^{-1}	.	1	1	15	2	1
Sewage sludge + mineral wool 800 m^3 ha^{-1}	.	1	1	12	1	1
Mineral wool 200 m^3 ha^{-1}	1	1	.	23	3	2
Mineral wool 400 m^3 ha^{-1}	.	1	.	28	3	2
Mineral wool 800 m^3 ha^{-1}	.	2	1	28	3	3
NPK + mineral wool 200 m^3 ha^{-1}	.	2	.	23	3	2
NPK + mineral wool 400 m^3 ha^{-1}	1	2	.	22	2	2
NPK + mineral wool 800 m^3 ha^{-1}	1	1	.	22	3	2
Min.	1	1	1	12	1	1
Max.	1	5	1	28	4	3
Average	1	2	1	22	3	2
Coefficient of variation	-	68.3	-	25.6	30.5	38.7

* Key under Figure 1

The analysis of the indicator of resistance to NaCl in the soil under the plot experiment shows the presence of so-called *facultative halophytes* (species tolerating an increased NaCl content) – Table 6. They represent 32.9% of the studied flora. The analysis of this indicator in the context of the type of waste used for reclamation indicates that most species exhibiting the resistance to an elevated NaCl content (indicator 1) grew on plots reclaimed with mineral wool, fewer on plots treated with mineral wool + NPK, and the fewest were found on plots with sewage sludge and mineral wool application.

Table 6

Influence of reclamation method on the number of plant species according to the resistance to NaCl content

Indicator NaCl resistance content (S)	Reclamation variants										
	NPK - control	sewage sludge	sewage sludge + mineral wool			mineral wool			mineral wool + NPK		
			200*	400	800	200	400	800	200	400	800
1	9	15	13	10	7	15	16	18	15	13	16

* 200, 400, 800 – doses of mineral wool in m^3 ha^{-1}

The study shows an increased content of heavy metals on the soilless formation reclaimed with sludge, sewage sludge and different doses of mineral wool. Elevated concentrations of heavy metals occurred in 11.8% of the examined flora. Our analysis of the resistance to an increased content of heavy metals (M) shows that the largest number of species with indicator 1 was found on soils reclaimed with mineral wool, slightly fewer on soil reclaimed with mineral wool and NPK fertilization, and the fewest - in the case of soil treated with sewage sludge and mineral wool (Table 7).

Table 7

Influence of reclamation method on the number of plant species according to the resistance to the increased heavy metals content

Indicator increased resistance to heavy metals content (M)	Reclamation variants										
	NPK - control	sewage sludge	sewage sludge + mineral wool			mineral wool			mineral wool + NPK		
			200*	400	800	200	400	800	200	400	800
1	3	3	5	2	3	6	6	6	6	5	6

* 200, 400, 800 – doses of mineral wool in m^3 ha^{-1}

DISCUSSION

The analysis of the trophic indicator for the reclaimed soilless formation has shown the presence of species with a broad spectrum of trophic requirements within the vascular flora of the examined habitats. Species with small nutritional requirements as well as ones of moderately poor and abundant, and even very abundant habitats, were documented. However, the dominant group were the species attributed to abundant (eutrophic) habitats. Research by Cabała, Jarząbek (1999) shows that a former landfill in Chorzow was dominated by species which preferred conditions typical of abundant soils. Klimko et al. (2004) indicate that the Wałbrzych dumping grounds used by the coal mines Thores and Victoria were also overgrown by species with different trophic requirements. However, the percentage of taxa with different trophic indicators was similar. According to Jędrzejko, Olszewski (2006), the largest group of plants in post-exploitation areas of four liquidated coal mines was composed of mesophilic species, whilst eutrophic and oligotrophic plants formed a small group.

The examined habitats of reclaimed soils were overgrown by plant species with different moisture requirements (from dry to wet). However, species preferring the moisture conditions typical of fresh soils were prevalent (indicator 3). Similar dependencies were observed during the research made by Cabała, Jarząbek (1999) on the former dumping grounds in Chorzow. In turn, Klimko et al. (2004) indicate that the Wałbrzych dumps were overgrown by flora with the predominance of wet habitat species (indicator 5).

Our analysis of the organic matter content indicates that species preferring conditions typical of mineral-organic soils dominated in the conditions created by the soilless formation reclamation methods submitted to our analysis. A similar dependence was suggested by CABAŁA, JARZĄBEK (1999).

In terms of the acidity indicator, the study of the reclaimed soilless formation reveals that the largest group was composed of species characteristic for neutral soils. This demonstrates that acidic degradation, as the main form of environmental degradation in the area affected by sulfur mining, has been effectively eliminated. CABAŁA, JARZĄBEK (1999) reported the presence of species preferring substrates with moderately acidic to slightly acidic pH in the former dumping grounds in Chorzow.

The study indicates the occurrence of species tolerating an increased content of NaCl and heavy metals in the soil in the examined area.

The analysis of the reclamation methods and their effects showed that the greatest diversity with respect to both the number of species and the analyzed ecological indicators was in the soilless formation reclaimed with mineral wool, lower – with mineral wool and fertilized with mineral fertilizers NPK, and the lowest – with the addition of sewage sludge and mineral wool. A much greater diversity of species in terms of the analyzed indicators was recorded in the control plot, which was fertilized with mineral NPK fertilizers.

CONCLUSIONS

1. The soilless formation devastated due to the acidic pressure and afterwards reclaimed with flotation sludge, municipal sewage sludge and waste mineral wool from crops grown under cover achieved the habitat conditions where the dominant were plant species preferring moist habitats, typical of fresh soils, with the trophism structure corresponding to the abundant soils (eutrophic), neutral pH, as well as anthropogenic soil with the organic matter content same as in mineral-humic soils.

2. Among the reclamation methods, the most favorable habitat conditions were created on the soilless formation reclaimed with mineral wool, slightly worse conditions were obtained through the application of mineral wool and NPK fertilization, while the least beneficial was the use of sewage sludge along with mineral wool.

3. A dose of mineral wool did not produce a univocal impact on ecological indicators (soil moisture content, acidity, trophism, organic matter content, resistance to salinity, and increased concentrations of heavy metals).

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