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Assessment of the Effectiveness of Soil Reclamation Techniques Degraded by the Sulfur Industry

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ABSTRACT

This article shows the results assessment of the impact of various reclamation methods with the use of mineral wool and municipal sewage sludge on chemical and biological indicators, which have an impact on the improvement of the quality of soil degraded by sulfur well mining. The results of the research showed that the type of waste together with it application method, had a beneficial effect on the shaping of the chemical and biological properties of soil. The most favorable effect was noted in the conditions of combining mineral wool with sewage sludge. At this work we used the PHYTOTOXIKIT biological test, as an indicator of the ecotoxicological effect of selected waste added, for the efficiency of the soil remediation process.

Keywords: degraded soil, soil reclamation techniques, sulfur industry, mineral wool, sewage sludge, biological test.

INTRODUCTION

The impact of multiple anthropogenic pressures is of particular importance on soil as a permanent landscape element. A particular example of this is sulfur borehole mining, which involves melting sulfur in the depths of the earth and bringing it to the surface in a closed pipeline system (Frash method). The seemingly safe method caused intensive degradation and devastation of the environment as a result of numerous failures, as well as deterioration of chemical, physicochemical, physical and biological properties [1–2]. The process is all the more intense as it concerns the environment with weak and defective native soils [1,3–4]. The above-mentioned conditions make the reclamation of these areas extremely difficult [5–8]. It requires the regulation of the reaction, the improvement of devastated properties and the regulation of moisture, necessary for effective biological reclamation. As shown by the research results so far [9–13], the improvement of the above properties can be obtained by shaping an appropriate resource of organic matter in the reclaimed land. Appropriate quality waste substances, ie municipal sewage sludge, post-consumer mineral wool, can be used for this purpose. These wastes, especially municipal sewage sludge, are produced in huge amounts and there is a huge problem with their use [14]. Difficulties with the management or neutralization of organic waste and minerals result from their chemical composition. An example would be the presence of heavy metals, mineral and organic toxic substances and other pollutants. Potential waste that can be managed in a natural way is post-consumer mineral wool and municipal sewage sludge. Depending on the quantity and quality of the generated sewage sludge and on local conditions, various methods of handling the sludge are used: depositing in landfills, disposal with thermal methods, natural use, including agriculture, reclamation, production of composts and biomass for energy purposes [15–18]. Currently, the storage of organic waste, containing a lot of biodegradable substances, is limited, hence there is a need for alternative management in the environment [19]. However, in the light of the new legal regulations, more and more stringent requirements for the natural use of organic and mineral waste appear [19–23]. Sewage sludge contains a high content of micronutrients and microelements, as well as organic substances, therefore they should be used as a substrate containing a valuable fertilizer source, which will ensure optimal and proper development of plants and at the same time improve the physicochemical properties of the soil [6,24–26]. The use of municipal sewage sludge and mineral waste is regulated by the ordinance of the Minister of the Environment [19–21]. Scientific literature shows that municipal sewage sludge, after being introduced into the soil, releases heavy metals into the environment as a result of mineralization of the organic substance contained in this waste [18, 24–25]. Rational use of mineral and organic waste in Poland is one of the most important social, economic and environmental problems. Considering these issues, much attention is paid to municipal, industrial and other waste. The first of them are related to the living and economic activity of man. They are found especially in larger urban or urban-industrial agglomerations as well as in rural areas. On the other hand, the source of industrial waste is primarily mining, energy and metallurgical industry [16,27]. Post-industrial waste includes, among others, waste from hydroponic farming, i.e. post-production mineral wool and other waste from various branches of production, such as post-flotation lime used in the research – waste used for soil deacidification [6,28–29].

The aim of this study was to assess the various techniques of degraded soil reclamation using waste such as post-flotation lime, municipal sewage sludge and Grodan post-consumer mineral wool, based on chemical and biological soil quality indicators.

MATERIALS AND METHODS

Materials description

The reclamation experiment was carried out at the site of the former “Jeziórko” Sulfur Mine (Poland, Podkarpackie, N50 ° 33′09 ″, E21 ° 46′40 ″). This region is characterized by an average annual rainfall of 550 to 650 mm and an average annual temperature of +8.2 ° C. Sulfur extraction was carried out using the Frash method. The experiment was set up on slightly loamy sand in order to verify the applied different technologies of mineral wool application to degraded soil in 2008. Various methods of degraded soil reclamation were used on microplate with an area of 30 m^2 each. Flotation lime (100 Mg · ha^{-1}) was used for deacidification of degraded soil (weak loam sand), and for fertilization with post-consumer mineral wool (Grodan) from Horticulture company in Nisko, against the meliorative background (100 Mg · ha^{-1}) of the dose of sewage sludge from municipal sewage treatment plant in Stalowa Wola (Table 1).

Flotation lime was spread using 2 C-360 tractors and manure spreaders and a K-162 backhoe loader. Sewage sludge and mineral wool were applied in doses according to the experimental design, using a manure spreader. Mineral wool was used when properly moistened in order to eliminate possible spraying while introducing it into the soil. Integration of the introduced substances and the applied mineral fertilizers with the soil was made with the use of a disc harrow and a rotary tiller. Mineral fertilizers (100% P and K and ½ N) were sown before sowing, and in the following years they were applied in spring. The other half of the nitrogen dose was applied after And the swath. A reclamation mixture of grasses was sown on the plots prepared in this way.

Table 1. Scheme of the microplate experiment

No	Reclamation variants
1	Degraded soil
2	Degraded soil + lime + NPK
3	Degraded soil + lime + sewage sludge 100 Mg·ha^{-1}
4	Degraded soil + sewage sludge 100 Mg·ha^{-1}
5	Degraded soil + 5 cm / 40 cm wool + lime + NPK
6	Degraded soil + 5 cm / 40 cm wool + lime + sewage sludge 100 Mg·ha^{-1}
7	Degraded soil + lime + NPK + wool 400 m^3·ha^{-1}
8	Degraded soil + lime + wool 400m^3·ha^{-1} + sewage sludge 100 Mg·ha^{-1}

Methods of soil reclamation

On microplate number 5 and 6, mineral wool (5 cm layer) was placed in the soil at a depth of 40 cm. On microplate number 7 and 8, the same dose of wool (400 m3 · ha^{-1}) was mixed with the soil at a depth of 0 to 25 cm. Microplate number 1 was the native soil (control), without any additives. Flotation lime and NPK mineral fertilization were applied on microplate number 2, and on microplate number 3 – flotation lime and sewage sludge in the dose of 100 Mg·ha^{-1}, and on microplate number 4, clean sewage sludge was applied (Fig. 1).

Soil samples for laboratory tests were collected in 2009 and 2019 at the end of vegetation (X). Grass samples were taken after each cut.

The quality indicators determination

Chemical properties

In the collected soil / soil samples and the tested waste, the following chemical properties were determined:

- potentiometric reaction in H2O and 1mol×dm^{-3} KCl,
- hydrolytic acidity (H_h) by the Pallmann method in 1 mol×dm^{-3} CH_3COONa,
- basic cations (S) in 0.5 mol×dm^{-3} ammonium chloride extract (pH 8.2),
- the sorption capacity (T) and the degree of saturation of the sorption complex with basic cations (V) were calculated.

Biological properties

The PHYTOTOXIKIT biological test was carried out on waste (mineral wool and sewage sludge) and their mixtures. The PHYTOTOXIKIT test was applied on 4 objects, with waste catalog numbers 170604 (post-consumer mineral wool), 190805 (municipal sewage sludge) in relation to the control soil (Table 2).

In the standard PHYTOTOXKIT test, the following effects were analyzed in the tested waste in relation to the control soil: the amount of germinating seeds, measurement of the root length, inhibition (decrease) of seed germination and inhibition of root growth. The PHYTOTOXKIT test has many advantages. First of all, it is easy and quick to prepare and does not require expensive laboratory equipment, therefore it can be a valuable supplement, or even an alternative to classical instrumental analyzes. It is worth noting here that the principle and procedure of the PHYTOTOXIKIT test is analogous to the ISO standards [30,31] „Determining the effects of soil contamination – Part 1. Method for measuring inhibition of root growth" and higher plants. Due to the fact that organisms differ in their sensitivity to various toxic substances, an important factor in toxicological studies is the selection of the appropriate test plants. The test plants should belong to different taxonomic groups to differ in their sensitivity to toxic agents. The test examined the toxicity of waste on 3 plants, such as watercress, mustard and sorghum. Two parameters were assessed: the number of germinating seeds and the measurement of the root length (Table 3).

Fig. 1. Vegetation experience related to the research (Photo by S. Baran)

Table 2. Objects used from the PHYTOTOXKIT test

No object	Combination	Participation in the mixture %
1	Control – degraded soil	100
2	Mineral wool	100
3	Mineral wool + sewage sludge	50:50
4	Mineral wool + degraded soil	50:50

The hazard classification system developed by Persoone et al. [32] (Table 4).

This system is based on two values: position in the 5-grade hazard class and the significance of the result for each class. The first stage was to perform screening tests on the analyzed wastes. The toxicity results obtained were then expressed as a percentage of the test reaction (PE%). After determining the percentage effect for each bioassay, the sample was classified into one of five classes based on the highest toxic value reported by at least one test.

Use of the PHYTOTOXKIT test

The analyzed waste and mixtures were placed on the test plates, successively wetted with distilled water to the maximum water capacity. The test plates with the mixtures were then covered with filter paper and 10 seeds of the test plants were sown per plate. The prepared plates were incubated in the dark for 3 days (72 hours) in an upright position at 25 ° C. The image was then recorded with a digital camera, and the image analysis program „Image Tools" was used to measure the root length. The entire experiment was carried out in 3 replications for each of the tested combinations (waste – plant). The percent inhibition of germination (IG) and root growth (IK) of the test plants was calculated according to the following formula:

$$IG / IR = [(A-B) / A] \cdot 100 \quad (1)$$

where: A – is the average for seed germination or root growth in control,
B – average B for seed germination or plant root growth in the tested mixtures.

Statistical analysis

The results of own research are summarized in tables and graphs, which were then statistically analyzed using the STATISTICA 5: Anova / Manova Version, ,97 Edition software. Tukey's confidence interval was used at the significance level of 0.05.

RESULTS AND DISCUSSION

Results of physical and chemical tests

A micro-plot experiment was established on the soil degraded by the sulfur industry in Jeziórka. The soil was characterized by weak loam sand graining and strong acidification. The sorption properties of this soil were unfavorable, with a predominance of hydrogen saturation and a low content of K and P assimilable forms (Table 5).

Other authors [5,9,18,33] had similar observations when analyzing poor quality (light) soils. Grodan mineral wool had favorable sorption properties – it had a high content of basic cations – 57.04 cmol (+) kg^{-1} and low hydrolytic acidity – 3.82 cmol (+) kg^{-1}. Overall, the degree of saturation with basic cations was high – 93.72% (Table 6).

This waste is characterized by a high content of available phosphorus and potassium, and the content of heavy metals is not objectionable. Zinc and copper are present in amounts that can contribute to the enrichment of fertilized and reclaimed soils. Lead and cadmium are present in concentrations lower than those allowed for soils and organic waste [19]. The high water retention capacity of mineral wool may have a positive impact on the process of biological reclamation of degraded soils and soil regeneration in devastated areas. Other authors [5–7,34], analyzing the properties of mineral wool, obtained similar research results. The reaction of municipal sewage sludge was close to neutral, the pH measured in 1 mole of KCl was 6.4 (Table 6). The sorption properties of this sediment were favorable: the sum of

Table 3. The PHYTOTOXIKIT bioassay kit

Level trophic	Test plants	Parameter	Time duration
Producers	Cress – *Lepidium sativum*	Inhibition sprouting and root growth	3 days
	White mustard – *Sinapis alba*		
	Sugar Sorghum – *Sorghum saccharatum*		

Table 4. Hazard classification by test reaction [32]

Percentage toxic effect (PE%)	Class	Danger
PE <20% no significant toxic effect, non-toxic sample	I	no acute threat
20% ≤ PE <50% significant toxic effect, low-toxic sample	II	low acute threat
50% ≤ PE <100% significant toxic effect, toxic sample	III	acute threat
PE – 100% (one test)	IV	high acute threat
PE – 100% (all tests)	V	very high acute threat

basic cations was 50.04 cmol (+) · kg^{-1}, and the hydrolytic acidity was 4.50 cmol (+) · kg^{-1}. The content of assimilable forms of phosphorus and potassium was, respectively: 17.02 mg · 100g^{-1} and 60.40 mg · 100g^{-1} (Table 6), which should be assessed as high [35]. In the studies by Sapek and Sapek [36], the phosphorus content in the sludge was very high, which made it a low-percentage phosphorus fertilizer, of which phosphorus is used in over 20%. Also in the research of Krzywy et al. [37], sewage sludge was characterized by a much higher phosphorus content than cattle manure [38–39]. The content of heavy metals in the sewage sludge was at the acceptable level [19,20]. The sewage sludge used also met sanitary requirements. Flotation lime was also characterized by favorable properties because the pH measured in 1 mole of KCl was 6.8, the sum of basic cations was 12.21 cmol (+) · kg^{-1}, and the saturation of the sorption complex with basic cations was 99.35%. This waste was characterized by a low content of available phosphorus, while the content of available potassium was 22.50 mg · 100g^{-1}. The heavy metal content was low. The soil degraded from the micropled experiment was strongly acidic (pH 4.7–5.5) (Table 7).

Table 5. Selected properties of degraded soil from the conducted experiment

Property	Unit	A microplet experience
Particle size distribution	% sand % dust % floatable parts	91 3 6
pH	H_20	5.40
pH	KCl	4.70
Hh	cmol(+)·kg^{-1}	4.20
S		2.02
T		6.22
V	%	32.50
Available phosphorus P	mg·100 g^{-1}	0.76
Available potassium K		2.38
Cu	mg·kg^{-1}	2.41
Zn		5.36
Pb		4.18
Cr		10.5
Ni		8.03
Cd		0.89
Hg		0.02

Table 6. Selected properties of Grodan post-consumer mineral wool, sewage sludge and post-flotation lime

Property	Unit	Mineral wool	Sewage sludge	Flotation lime
Particle size distribution	% sand % dust % floatable parts	n.o.	n.o.	35 29 36
pH	H_20	5.8–6.9	6.8	7
pH	1 molowy KCl	5.3–6.6	6.4	6.8
Hh	cmol(+)·kg^{-1}	3.82	4.5	0.8
S		57.04	50.04	122.1
T		60.86	54.54	122.9
V	%	93.72	91.7	99.35
available phosphorus P	Mg·100 g^{-1}	11.96	17.02	0.002
available potassium K		32.01	60.4	22.5
Cu	mg·kg^{-1}	42.75	139	13
Zn		133.5	935	49
Pb		35.5	29.2	29
Cd		0.5	3.45	1.2
Cr		18.5	26.7	12.8
Ni		9.3	55.1	68
Hg		Śl.	0.45	Śl.

Results of the applied reclamation technique on soil properties

The addition of post-flotation lime, sewage sludge and mineral wool increased the pH value in the first test period, the pH ranged from 6.1–6.7. On the other hand, in the second study period (2019), the pH value decreased in all reclamation variants. The research shows that where sewage sludge was applied to the soil, the greatest differences were noted. The sorption capacity of native soil was 2.5 times smaller than that of the reclaimed soil, it was 6.2 cmol (+) kg^{-1} (Table 8).

The sorption capacity in the soil reclaimed with various additives was 14.5–17.5 cmol (+) kg^{-1}. The soils where only sewage sludge was used had the lowest sorption capacity (Table 6). Other authors [7,40] confirm in their research that the reclamation of soils damaged by the industry with the use of mineral wool and sewage sludge against the background of post-flotation lime significantly influenced the amount of sorption capacity.

Table 7. Exchange acidity (pH in 1 mol KCl) in reclaimed soil

Reclamation variants	Deadlines	
	I	II
Degraded soil	4.7	5.5
Degraded soil + lime + NPK	6.4	5.9
Degraded soil + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	6.3	5.9
Degraded soil + sewage sludge 100 $Mg \cdot ha^{-1}$	6.1	4.8
Degraded soil + 5 cm / 40 cm wool + lime + NPK	6.7	5.6
Degraded soil + 5 cm / 40 cm wool + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	6.6	5.8
Degraded soil + lime + NPK + wool 400 $m^3 \cdot ha^{-1}$	6.7	6.0
Degraded soil + lime + wool 400 $m^3 \cdot ha^{-1}$ + sewage sludge 100 $Mg \cdot ha^{-1}$	6.6	6.0

The sums of basic cations in the soil subjected to reclamation ranged from 12.1 – 16.3 cmol (+) kg^{-1} (Table 6). Basic cations dominated in the sorption complex of reclaimed soil, where the degree of saturation ranged from: 62.01–92.83%. In the native soil it was low and amounted to 27.4%. The method of wool application did not affect the amount of sorption capacity, while the addition of flotation lime clearly increased this property (Table 8). In the reclaimed soil with the addition of wool, regardless of its application, in the second study period, a higher sorption capacity was observed compared to the first year (Fig. 2).

Results of the PHYTOTOXIKIT biotest

The use of waste such as: mineral wool and municipal sewage sludge in the natural economy is possible when we transform them into substrates with parameters that meet the environmental protection requirements. The research shows that among the tested wastes and their mixtures, the weakest reaction of inhibiting germination of test plant seeds was demonstrated in object 3, i.e. a mixture of mineral wool + sewage sludge, and the strongest phytotoxic effect was found in object 2, i.e. only on the mineral wool used. Standard soil was used as a control sample of the seed germination inhibition reaction. The control soil had the least effect on the germination inhibition of the test plants. The root length of the tested plants and the number of germinating seeds varied. It depended on the plant species and the type of substrate (Table 9).

The conducted research shows that all mustard seeds germinated, while in the case of watercress, the mineral wool influenced the germination of 9/10 of the sown seeds (Table 9). The analysis of sorghum seeds showed that only mineral

Table 8. Sorption properties of reclaimed soil in 2008–2019. Average values

Reclamation variants	T	S	H^+	V
	cmol(+)kg^{-1}			%
Degraded soil	6.2	4.5	1.7	27.46
Degraded soil + lime + NPK	15.8	14.5	1.3	91.70
Degraded soil + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	15.2	13.0	2.2	85.49
Degraded soil + sewage sludge 100 $Mg \cdot ha^{-1}$	14.5	12.1	2.4	62.01
Degraded soil + 5 cm / 40 cm wool + lime + NPK	15.5	13.6	1.9	87.60
Degraded soil + 5 cm / 40 cm wool + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	16.4	14.2	2.2	86.51
Degraded soil + lime + NPK + wool 400 $m^3 \cdot ha^{-1}$	17.5	16.3	1.2	92.83
Degraded soil + lime + wool 400 $m^3 \cdot ha^{-1}$ + sewage sludge 100 $Mg \cdot ha^{-1}$	15.3	13.4	1.9	88.24
$NIR_{0,05}$ between the terms	22.84*	20.83*	11.79	5.67
$NIR_{0,05}$ between remediation methods	79.59**	72.61**	41.09	19.78**

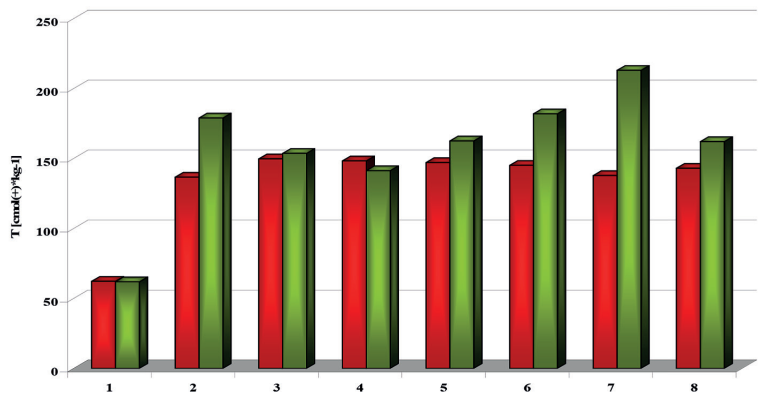

Fig. 2. he sorption capacity of the reclaimed soil in the studied period and variants of reclamation. Average values

wool influenced the germination of all seeds, and in the remaining locations, seed germination was found in 9/10 sown. The length of the plant roots was also examined, which was also varied. This property depended on the plant species and the type of substrate (Table 10).

The greatest influence on the root length was exerted by mineral wool, which is confirmed by the conducted research. The shortest root length of the test plants was recorded on rockwool compared to other objects. The greatest inhibition of germination was found in watercress, where mineral wool was used. The degree of inhibition of the sprouting of cress seeds ranged from 0 to 15%, and sorghum from 0 to 6%. The mustard seeds showed that germination was not inhibited. The second parameter assessing the toxicity of the tested wastes, and their mixtures, was the growth of young plant roots (Table 8). The results of the studies show that the strongest phytotoxic effect of wastes and mixtures on the root growth of the studied plants was observed in the facility with mineral wool, ranging from 44 to 86%. The weakest reaction of inhibiting the growth of young roots of the test plants was found in object 3 (mineral wool + municipal sewage sludge) and ranged from 19 to 43%. The plant most resistant to phytotoxic effects of the mixtures turned out to be sorghum (*Sorghum saccharatum*), then white mustard (*Sinapis alba*), and the most sensitive plant was cress (*Lepidium sativum*). To sum up, the ecotoxicity of waste and its mixtures can be classified according to the toxicity in the following order: mineral wool> mineral wool + soil> mineral wool + sewage sludge> soil. Based on the classification by Persoone et al. [32] assessed the toxicity of waste. In studies by many authors [41–42] it is considered that samples with a percentage of the toxic effect in the range of 50% ≤PE <100% are toxic. If the percentage of toxic effect is PE <20%, the authors write about no significant toxic effect, while when the percentage of toxic effect is between 20% ≤PE <50%, the sample is considered to be of low toxicity [41,42]. Taking this criterion, it was found that mineral wool with the catalog number 170604 (object 2) is toxic. On the other hand, the mixture of mineral wool and sewage sludge (object 3) and the mixture of mineral wool and soil (object 4) were found to be low-toxic for the test plants.

Results of the application of mineral wool on grass yield

The effect of the method of mineral wool application on the yield of grass (microfleece experiment) turned out to be significant (Tables 11, 12).

Table 9. Number of germinated seeds and root length of test plants

Object	Mustard (*Sinapis alba*)		Cress (*Lepidium sativum*)		Sorghum (*Sorghum saccharatum*)	
	Germination	Root length (mm)	Germination	Root length (mm)	Germination	Root length (mm)
1.Control – soil	10	61.5	10	55.7	9	16.2
2. Mineral wool	10	13.7	9	7.6	10	9.2
3. Mineral wool + sewage sludge	10	49.0	10	45.2	9	23.2
4. Mineral wool + soil	10	38.7	10	37.4	9	18.4

Table 10. Inhibition of root growth and germination of test plants (%)

Object	% Inhibition of germination			% Inhibition of root growth		
	Mustard *(Sinapis alba)*	Cress *(Lepidium sativum)*	Sorghum (*Sorghum saccharatum)*	Mustard *(Sinapis alba)*	Cress *(Lepidium sativum)*	Sorghum (*Sorghum saccharatum)*
1. Control – soil	0	0	0	0	0	0
2. Mineral wool	0	15	0	78	86	44
3. Mineral wool + sewage sludge	0	0	0	20	19	43
4. Mineral wool + soil	0	0	6	37	33	13

Table 11. Grass yield from the micro-field experiment

Reclamation variants	Yield in 2009		Yield in 2019	
	$Mg \cdot ha^{-1}$	Relative yield (%)	$Mg \cdot ha^{-1}$	Relative yield (%)
Degraded soil	1.35	100.00	1.57	100.00
Degraded soil + lime + NPK	3.50	259.26	2.90	184.71
Degraded soil + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	4.80	355.56	3.36	214.01
Degraded soil + sewage sludge 100 $Mg \cdot ha^{-1}$	4.50	333.33	3.29	209.55
Degraded soil + 5 cm / 40 cm wool + lime + NPK	6.40	474.07	6.10	388.54
Degraded soil + 5 cm / 40 cm wool + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	6.80	503.70	6.75	429.94
Degraded soil + lime + NPK + wool 400m^3 ha^{-1}	6.60	488.89	6.65	423.56
Degraded soil + lime + wool 400m^3ha^{-1} + sewage sludge 100 $Mg \cdot ha^{-1}$	7.10	525.93	7.90	503.18

Table 12. Total grass yield obtained in 2009–2019. A microplate experience

Reclamation variants	Yield in the studied years (Mg)	Relative yield (%)	Relative yield (%)
Degraded soil	2.92	100.0	-
Degraded soil + lime + NPK	6.40	219.2	100.0
Degraded soil + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	8.16	279.5	127.5
Degraded soil + sewage sludge 100 $Mg \cdot ha^{-1}$	7.79	266.8	121.7
Degraded soil + 5 cm / 40 cm wool + lime + NPK	12.5	428.1	195.3
Degraded soil + 5 cm / 40 cm wool + lime + sewage sludge 100 $Mg \cdot ha^{-1}$	13.55	464.0	211.7
Degraded soil + lime + NPK + wool 400 $m^3 \cdot ha^{-1}$	13.25	453.8	207.0
Degraded soil + lime + wool 400 $m^3 \cdot ha^{-1}$ + sewage sludge 100 $Mg \cdot ha^{-1}$	15.00	513.7	234.4

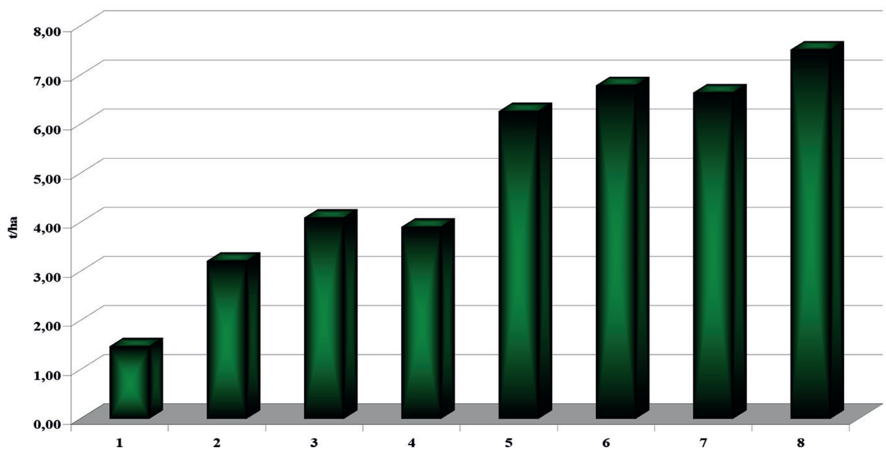

Fig. 3. Total yield of fresh grass mass from the microplate experiment

The highest total yield of grass was obtained from the soil with the addition of sewage sludge and mineral wool distributed in the top layer, and it was 513.7% higher compared to the yield obtained on native soil and 234.4% obtained on limed and fertilized with NPK soil. Mineral wool arranged in the topsoil had a more favorable effect on the yielding of grass than that arranged as a layer in the soil profile. The grass yield was 25.7% in the conditions of simultaneous NPK fertilization and 49.7% when using sewage sludge (reference to the native soil) (Table 11) compared to the soil profile, it was lower, but higher compared to the control by 374%. The yield capacity of the native soil reclaimed with the use of mineral wool and sewage sludge was much higher and more stable (Fig. 3).

Gilewska [43–44] draws attention to the beneficial effect of mineral wool used in the reclamation of a dump in the Brown Coal Mine, on the yield of plants. Other authors [45–49] analyzed the yield of plants using waste, especially sewage sludge, obtained similar or different research results.

CONCLUSIONS

Positive results were obtained when analyzing the effectiveness of soil reclamation techniques degraded by the sulfur industry. The soil devastated by the sulfur industry, on which the microfield experiment was carried out, was characterized by strong acidification. Municipal sewage sludge and post-production mineral wool from horticultural crops under cover were characterized by favorable sorption properties. Mineral wool additionally had a high water retention capacity. The addition of waste positively influenced the improvement of selected soil properties. Taking into account the waste toxicity criterion, it was concluded that mineral wool used alone is quite toxic waste. On the other hand, the mixture of mineral wool and sewage sludge and the mixture of mineral wool and soil were found to be low-toxic for the test plants.

Reclamation of soils heavily devastated by the sulfur industry had a positive effect on the yielding of grasses.

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