JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(2), 47–53
https://doi.org/10.12911/22998993/130877
ISSN 2299-8993, License CC-BY 4.0

Received: 2020.11.16
Accepted: 2020.12.14
Published: 2021.01.01

The Changes in Physicochemical Properties in Soils Subjected to Many Years of Reclamation

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ABSTRACT

The work under the conditions of the micropark experience analyzes the impact related to the method of mineral wool application and various reclamation methods on the physicochemical changes in the soilless track devastated by mining sulfur. Our results showed that the tested waste, as well as its manner of application to the soil, had a positive influence on the physical and chemical properties of degraded soils. The most beneficial impact was recorded under the conditions of the mineral wool association in the top layer of the soil (0–25 cm) of sewage sludge.

Keywords: land reclamation, soilless track, mineral wool, sewage sludge

INTRODUCTION

The sulfur mine in Jeziórko exhibits a soil environment that is heavily degraded and devastated. Sulfur was mined in this area by using the underground smelting method known as the Frash method. This method was an innovative technology that resulted in specific transformations of the natural environment, in particular of the soil environment. In the Jeziórko sulfur mine, a much more environmentally friendly technique of extracting the sulfur by melting it from the rock mass was used. This method, despite its undoubtedly positive features for the natural environment (no need to remove the overburden and create dumps and deep excavations), caused intensive degradation of the chemical, physicochemical, and biological properties of the soils, often to the state of devastation [Kaniuczak 2007, Knap et al.2016, Warzybok 2000, Martyn and Jońca 2006, Józefowska et al. 2016, Olson 2010, Siuta 2016].

The transformations caused by sulfur mining result from this chemically active mineral, its historically conditioned environmental properties, and the mining process itself. In the mining process, native sulfur, sulfides, and sulfur oxides are a potential source of sulfuric acid in the soils, leading to a decrease in the pH and creation of toxic conditions for most plants, including a huge shortage of nutrients and increased mobility of the phytotoxic elements [Warzybok 2000, Martyn and Jońca 2006].

Reclamation of post-mining areas after sulfur borehole mining is very difficult and takes a long time [Cui, Jun, et al., 2012] As a result of the mining activities and the poor quality of the native land, there is frequently a water shortage; this is an important factor that reduces the effects of biological reclamation. Sulfur is an essential element for plant life. Both its excess and its deficiency in the soil environment can be harmful to the growth and development of plants [Baran, 2008, Bryk and Kołodziej, 2009, Ellis and Atherton, 2003; Healy and Hickey, 2002; Wolff, 1992, An et al., 2007, Olson et al., 2013, Ossola et al., 2015, Joniec, 2019, Bowszys et al., 2015].

The sulfur mine in Jeziórko is a good example of soil acidification that resulted from the mechanical pressure under the influence of borehole sulfur extraction. In the soils that have been strongly acidified, alkaline components are displaced and washed away, mineral deposits and organic acids are accumulated, and there is a release of hydrogen ions as a result of the uptake of cations by plants [Baran et al. 2008, Czajkowski et al. 2009].

The long-term research cycle of post-mining land reclamation for sulfur mining is highly problematic [Zedler and Kercher, 2005, Hu et al., 2008; Yoon, 2009; Zou et al., 2011]. New ways of restoring degraded soils are constantly being sought. One way is to apply waste materials for reclaimed land, especially Grodan mineral wool.

Mineral wool is waste that was first produced in 1969 by Bor and Knoblauch in Denmark. It is currently the most widely used and well-known medium in the horticultural production in the world. This waste is a natural product that is made from igneous rocks. Mineral wool is formed from crushed igneous rocks, i.e., from basalt and diabase rock; it is ground with limestone and coke and then melted at 1600°C–2000°C. The resulting material is poured onto rotary drums, pulled into a thread with a diameter of approximately 0.05 mm, and then pressed in the form of mats [Oświęcimski, 1996, Siwik et al., 2018].

Mineral wool is a product that can be used in a maximum of two production cycles under cover, after which it becomes waste. It is a problematic waste product due to large volumes of it not being accepted at landfill sites. In Western countries, this waste product is processed into insulation wool; this is the best disposal idea but is not always economically and/or technically feasible. This waste can also be used, in combination with peat, for seedling vegetables, gardening, or balcony plants. This is a beneficial use, but does not completely solve the problem of its management. An interesting way of managing waste mineral wool is to use it to improve the quality of degraded soils. However, mineral wool in itself does not contain much organic matter, so it is advantageous to combine it with other organic waste [Baran et al., 2010, Joniec et al., 2015].

The aim of this study was to assess the impact of post-use mineral wool application from crops under cover and sewage sludge on the changes of physicochemical properties of degraded and devastated soils.

SCOPE AND METHODS OF RESEARCH

Micropark experience

On a soilless area (poor, loamy sand), a micro-field experiment was established in 2008, the purpose of which was to assess the possibility of applying various technologies of mineral wool to a soilless area. On micropores, each with an area of 30 m^2, different methods of reclamation of the native soil were used (Table 1, Photo 1).

Mineral wool (a 5-cm layer) was placed on micro-points 2 and 3 at a depth of 40 cm. An

Table 1. Experimental design

No.	Variants of reclamation
1	Native land
2	Soil + wool 5 cm / 40 cm + lime + NPK
3	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha
4	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha

Phot. 1. Micropark experience. Various technologies of reclamation of devastated soil using waste (sewage sludge, flotation lime, mineral wool).

identical dose of wool (400 m^3/ha) was integrated into the soil in the 0–25 cm layer for Micro-field No. 4. Microplot No. 1 was the native ground (control), without any additions. The micro-seed was sown with a reclamation mixture of grasses with the following species composition: fescue (Festuca pratensis), 41.2%; red fescue (Festuca rubra), 19.2%; perennial ryegrass (Lolium parenne), 14.7%; perennial ryegrass (Lolium multiflorum), 12.4%; cocksfoot (Dactylis glomerata), 6.5%; and red clover (Triforium pratense), 6%. The soil samples for testing were taken on two dates (2017, 2018) at the end of the vegetation, and were subjected to laboratory analysis.

The collected soil/soil samples and tested waste were marked with:

- granulometric composition using the Prószyński method in Casagrande modification,
- potentiometric reaction in H_2O and 1 mol/dm^3 KCl,
- hydrolytic acidity (Hh) by the Pallmann method in 1 mol/dm^3 CH3COON,
- basic cations (S) in an extract of 0.5 mol/dm^3 ammonium chloride (pH, 8.2),
- the sorption capacity (T) and the degree of saturation of the sorption complex with basic cations (V) were calculated.

The obtained results are presented in tables and figures and were statistically elaborated using the STATISTICA 5 program: Anova/Manova Version, 97 Edition. The statistical analysis used Tukey's confidence interval at a significance level of 0.05.

RESULTS AND DISCUSSION

The micro-field experiment was carried out on a devastated soilless mine in the area of influence of the Jeziórko sulfur mine. The ground had a granulometric composition of low-clay sand and was characterized by strong acidification and poor sorption properties with the dominance of hydrogen saturation (Table 2).

Grodan mineral wool from horticultural crops under cover was found to have favorable sorption properties, particularly a high content of basic cations (57.04 cmol (+)/kg); this, together with a relatively low hydrolytic acidity of 3.82 cmol (+)/kg, gave a high degree of saturation with basic cations, amounting to 93.72% (Table 3). Mineral wool has a high water-holding capacity, which can have a very beneficial effect on the biological reclamation process of degraded soils and the recovery of devastated soils.

The composition of mineral wool is as follows: silicon, 47%; calcium,16%, aluminum, 14%; magnesium, 10%, iron, 8%, sodium, 2%, as well as manganese and titanium at 1% [Komosa, 1998]. This waste has favorable properties: the porosity is 95–97% volume, the water capacity is 87%, the pH is not higher than 7.0 and it contains mineral components [Wysocka-Owczarek, 2001; Joniec et al., 2015]. Mineral wool contains large amounts of magnesium, calcium and nitrogen, and potassium phosphorus in a form with high absorption. The content of heavy metals is unquestionable [Baran et al., 2010, Baran et al., 2012, Joniec et al., 2015].

The results obtained by Jaroszczuk-Sierocińska [2007] reveal the excellent physical properties of this waste. Grodan wool is characterized by a very large water capacity and a water-containing capacity,; simultaneously, the air content is almost equal to the limit value. It is also important that as much as 90% of the entire water capacity is water that is most easily available to plants. Moreover, Baran [2008], found favorable sorption properties and a high water-retention capacity [Olson, 2010; Olson et al. 2013].

The municipal sewage sludge was characterized by a neutral pH; the pH measured in 1 mole of KCl was 6.4 (Table 3). This sludge had favorable sorption properties. The sum of the basic cations was 50.04 cmol (+)/kg, while the hydrolytic acidity was 4.50 cmol (+)/kg. This waste was characterized by a high carbon and nitrogen content of 193.8 and 28.0 g/kg, respectively. The C:N ratio was 6.9. In addition, many researchers indicated sewage sludge to be a rich source of Corg and N

Table 2. Selecting properties devastated soil from the ongoing experience

Property	Unit	Micropark experience 0–20 cm
Grain composition	% sand % dust % navigable parts	91 3 6
pH	H_20	5.40
pH	KCl	4.70
Hh	cmol(+)/kg	4.20
S	cmol(+)/kg	2.02
T	cmol(+)/kg	6.22
V	%	32.50

Table 3. Selected properties of postconsumer mineral wool Grodan, sludge and flotation lime

Property	Unit	Mineral wool	Sewage sludge	Flotation lime
Grain composition	% sand % dust % navigable parts	n.o.	n.o.	35 29 36
pH	H_20	5.8–6.9	6.8	7.0
pH	1 M KCl	5.3–6.6	6.4	6.8
Hh	cmol(+)/kg	3.82	4.50	0.8
S		57.04	50.04	122.1
T		60.86	54.54	122.9
V	%	93.72	91.7	99.35

[Baran et al., 2008; Wójcikowska-Kapusta et al., 2012; Żukowska et al., 2012, Czekała, Jakubus, 1999, Krzywy et al., 2000, Olson et al., 2013].

The flotation lime had favorable properties. The pH measured in 1 mole of KCl was 6.8; and the sum of the basic cations was 12.21 cmol (+)/kg (Table 3). The saturation of the sorption complex with bases was 99.35%. The native soil from the microplot experiment was characterized by a strongly acidic pH (pH 4.5–6.7). In the first year of the experiment, the addition of flotation lime, sewage sludge, and mineral wool caused an increase in the pH value. In the soil with the individual variants, the pH was in the range of 4.7–6.7. In the second year, the pH value decreased in all the reclamation variants, but the largest differences were recorded in the soil where wool was used at a depth of 40 cm, with the addition of sewage sludge (Table 4).

Martyn et al. [2001, 2006] and Klimont et al. [2001] confirm, in their research, that flotation lime associated with sewage sludge improves the properties of soil formations. The sorption capacity of the native soil was almost 50% less than the reclaimed soil, amounting to 6.20 cmol (+)/ kg (Table 5). In the soil reclaimed using various additives, the sorption capacity was in the range of 14.30–18.19 cmol (+)/kg.

According to the scope of various reclamation variants, the soil on which the sewage sludge and mineral wool were used in the crushed form was characterized by the lowest sorption capacity (Table 5). Moreover, in the studies of Baran et al. [2008a], reclamation of a soilless deposit with the use of mineral wool and sewage sludge, against the background of flotation lime and NPK fertilization, significantly affected the volume of the sorption capacity. The reclamation variants and the application of mineral wool had a significant impact on the sorption capacity. The most beneficial effect on the property in question was the addition of sewage sludge with a mineral wool inserted at a depth of 40 cm (Table 5). In the first test period, the sorption capacity was lower than

Table 4. Exchangeable acidity (pH 1 M of KCl) in a layer 0–20 cm the reclaimed soil

No.	Variants of reclamation	Deadlines	
		I	II
1.	Native land	4.7	4.5
2.	Soil + wool 5 cm / 40 cm + lime + NPK	6.7	5.8
3.	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha	6.6	5.6
4.	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha	6.6	6.0

Table 5. Sorption capacity reclamation of land from the experience

No.	Variants of reclamation	T (cmol(+)/kg)		Average
		Term I	Term II	
1.	Native land	6.22	6.18	6.20
2.	Soil + wool 5 cm / 40 cm + lime + NPK	14.70	16.25	15.48
3.	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha	14.51	18.19	16.35
4.	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha	14.30	16.20	15.25
$NIR_{0.05}$ between dates		2.92		
$NIR_{0.05}$ between remediation variants		6.25*		

in the following year; this could have been caused by the use of these wastes (Table 5). The content of the sum of the basic cations in the reclaimed land with the discussed variants was in the range of 12.50–15.79 cmol (+)/kg (Table 6).

On the basis of the conducted tests, an average nine-fold increase in the content of the basic cations in the sorption complex was noted compared to the native soil without any additives. The differences between the study dates were small. On average, the highest increase in the sum of rules was observed for the variant of soil fertilization with flotation lime, together with the addition of sewage sludge and mineral wool placed in the profile as an insert at a depth of 40 cm (Table 6). Statistical analysis shows that the content of the sum of the basic cations had a significant impact on the reclamation variant. The results of the research carried out by Baran (2008) and Jaroszczuk-Sierocińska [2007] confirm that mineral wool has a high content of basic cations, which has a positive effect on the sorption capacity of the analyzed soil.

The content of H^+ hydrogen cations in the soil ranged from 1.60–4.80 cmol (+)/kg. The highest content was found in both terms, in the ground without waste additives (Table 7).

The analysis of the content of H^+ hydrogen ions showed, on average, a 1.5-fold decrease in the content of these ions after the application of waste. The differences between the study dates were small. However, analyzing the average of both terms, it can be seen that the largest decrease in hydrogen ions was noted for the variant with sewage sludge and the application of ground mineral wool at a dose of 400m^3/ha. The reclamation variant was an important factor that affected the content of H^+ hydrogen cations (Table 7). The

Table 6. Contents of the sum of base cations in the sorption complex reclamation of land from the experience

No.	Variants of reclamation	S (cmol(+)/kg)		Average
		Term I	Term II	
1.	Native land	2.02	1.38	1.70
2.	Soil + wool 5 cm / 40 cm + lime + NPK	12.50	14.65	13.58
3.	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha	12.51	15.79	14.15
4.	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha	12.70	14.20	13.45
$NIR_{0.05}$ between dates		2.62		
$NIR_{0.05}$ between remediation variants		5.62**		

Table 7. Contents of hydrogen H + cations in the soil of experience

No.	Variants of reclamation	H^+ (cmol(+)/kg)		Average
		Term I	Term II	
1.	Native land	4.20	4.80	4.50
2.	Soil + wool 5 cm / 40 cm + lime + NPK	2.20	1.60	1.90
3.	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha	2.00	2.40	2.20
4.	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha	1.60	2.00	1.80
$NIR_{0.05}$ between dates		0.86		
$NIR_{0.05}$ between remediation variants		1.85*		

Table 8. The degree of saturation of sorption complex with basic cations in the experiment

No.	Variants of reclamation	V (%)		Average
		Term I	Term II	
1.	Native land	32.50	22.42	27.46
2.	Soil + wool 5 cm / 40 cm + lime + NPK	85.04	90.16	87.60
3.	Soil + wool 5 cm / 40 cm + lime + sewage sludge 100 Mg/ha	86.22	86.81	86.51
4.	Soil + lime + wool 400 m^3/ha + sewage sludge 100 Mg/ha	88.82	87.66	88.24
$NIR_{0.05}$ between dates		10.14		
$NIR_{0.05}$ between remediation variants		21.73**		

results obtained by Baran et al.[2008] confirm the decrease in the hydrogen ion content in relation to the control soil. Saturation of the sorption complex with basic cations (V) was withinthe range from 22.42–90.16% (Table 8). The degree of saturation of the soil complex with alkaline cations was significantly improved after the use of reclamation variants. The differences between the study dates were within 10%. The addition of sewage sludge together with the application of crushed wool at a dose of 400 m^3/ha turned out to be the best solution (Table 8).

CONCLUSIONS

The obtained test results showed that:

1. Mineral wool (Grodan), as a waste from horticultural production under cover, is characterized by favorable sorption properties, a high content of basic cations, low hydrolytic acidity, and a high water-retention capacity.
2. On the examined dates, in the variants with the addition of waste, there were trends of increase or stabilization of the values of the analyzed properties, while under the influence of NPK, the changes were insignificant. This proves that the properties of the reconstructed soil stabilize; this is also confirmed by comparing the properties with the results of other authors.
3. The application of mineral wool in the top layer of soil (0–25cm) had a more favorable impact on shaping the analyzed properties than its placement in the profile as an insert at a depth of 40 cm.

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