Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 18(8), 281–290
https://doi.org/10.12913/22998624/194129
ISSN 2299-8624, License CC-BY 4.0

Received: 2024.09.26
Accepted: 2024.10.14
Published: 2024.11.01

Assessment of the Effectiveness of Open-Cast Sand Mine Reclamation

Grażyna Żukowska[1], Magdalena Myszura-Dymek[1*], Zofia Durczyńska[2*],

[1] Faculty of Agrobioengineering, Institute of Soil Science, Environment Engineering and Management, University of Life Sciences in Lublin, ul. St. Leszczynskiego 7, 20-069 Lublin, Poland

[2] Nicolaus Copernicus University, Collegium Medicum, ul. Jagiellonska 13/15, 85-067 Bydgoszcz, Poland

* Corresponding author's e-mail: magdalena.myszura-dymek@up.lublin.pl, zofia.durczynska@gmail.com

ABSTRACT

The aim of the study was to assess the effect of sewage sludge (industrial and municipal) as components of composites with anthropogenic soil, used to create the top (0–25 cm) cover layer of open-cast sand mine reclamation on the content of organic carbon and plant nutrients (total N and available forms of P, K and Mg). In the excavation after sand mining, a reclamation technology was used, including filling the excavation with waste and producing Technosol using technical methods. The assessment of the effects of open-cast sand mine reclamation with waste showed that the reclamation cover made of waste meeting the ecological safety criteria was a good substrate for the emerging technogenic soil. The composite created from anthropogenic soil with the addition of sewage sludge (10:1) was characterized by a higher content of organic carbon, total nitrogen and available forms of P, K and Mg compared to anthropogenic soil fertilized with NPK fertilizers and manure. Monitoring of the surface layer properties (0–20 cm), carried out two years after introducing vegetation to the reclaimed area, showed that the assessed technology of reclamation of the excavation after sand mining using waste is a good way to solve the problem of dry areas devastated by open-cast mining of mineral deposits. Moreover, such waste management is in line with the strategy of the Circular Economy.

Keywords: open-cast sand mine reclamation, sewage sludge, TOC, TN, available forms of P, K and Mg.

INTRODUCTION

Soil is a fundamental and multi-functional component of all terrestrial ecosystems. It is classified as a non-renewable resource due to its lengthy formation process. At the same time, it has the potential to be rapidly degraded, and its regeneration processes are slow [Van-Camp et al., 2004], which forces entrepreneur civilisations to protect and use soil in accordance with the principles of sustainable development [1].

As a permanent landscape component, soil is particularly vulnerable to anthropogenic pressures, resulting in its degradation and even devastation. This leads to a reduction in the ability of soils to perform their productive and ecological functions, which poses a hazard to the food chain and the health of society [2]. Mineral resources mining, when carried out using the opencast method, is characterised by significant interference with the natural environment [3]. Opencast mineral mining results in multi-directional transformations of the landscape and land surface [4]. Abandoned mining excavations are a particular form of degradation in these areas, formed after intensive deposit exploitation when the post-production waste is not returned to them. The depth of abandoned mining excavations ranges from a few to several metres. The substrate comprises a variety of geological formations, most commonly sands, gravels, loams and clays. Depending on the permeability of geological formations, the bottoms of excavations may be dry, excessively wet or completely waterlogged [5].

An entrepreneur engaged in mineral extraction is obliged to carry out reclamation work within mining excavations [6]. According to the definition, reclamation involves "processes that impart or restore the usable or natural value to degraded land through appropriate shaping of the relief or the improvement of physical and chemical properties, the regulation of water relations, and the restoration of soils" [7]. Effective and durable reclamation of post-mining areas requires an interdisciplinary approach leading to an integrated and effective proposal to restore the ecological, hydrological, aesthetic, recreational and other functions of the post-mining landscape. The method of reclamation and the potential future management of post-mining areas depends primarily on the nature of the land surface, soil conditions, and the communal structure of the surrounding area to be reclaimed using technical, biological, agricultural, or forestry means [8].

In the case of dry-ground post-extraction excavations, one of the reclamation methods is to fill them with waste and create an upper reclamation layer, which has a decisive influence on the effectiveness of reclamation and natural land management [9, 10, 11].

The Regulation of 11 May 2015 of the Minister of the Environment on the recovery of waste outside of installation and equipment [12] enables the use of waste for the reclamation of degraded land. According to Annex 1 of this Regulation, it is possible to use the waste listed in the R3 and R5 recovery processes to fill the sinkholes and excavations that have been exploited. These operations are feasible when: (1) they are specified in planning documents (area development plan, land use plan) or in the Decision on reclamation and management under the Act of 3 February 1995 on the protection of agricultural and forest land, (2) these operations will not pose an immediate hazard of harm or damage to the environment, in accordance with the provisions of the Act on the prevention of environmental damage and its remediation [13], (3) the filling with waste is carried out to the level of the adjacent non-transformed land, and the surface layer with a thickness of 1-1.5 m must fulfil the soil-forming function or correspond to the target purpose of the area.

The dominant feature of degraded and devastated soils is the lack or much lower content of organic matter compared to neighbouring natural areas. The loss or removal of the top soil layer results in an immediate reduction in the organic matter pool in the soil [14]. When filling post-mining excavations, and especially when shaping the reclamation cover (surface layer) with mineral waste, it is necessary to supplement its composition with organic matter. To achieve a significant and sustained increase in the organic carbon content of the substrates being developed, it is necessary to incorporate significant amounts of organic matter. These requirements are fulfilled, e.g. by sewage sludge [15].

Studies by numerous authors have demonstrated the favourable effect of sewage sludge on the improvement of soil properties in degraded areas [16-22]. It is an organic material with beneficial soil- and humus-forming properties. It is also rich in organic matter and micro- and macroelements that are essential for plant growth and improve the biological activity of soils [23]. Composts and sewage sludges used for the reclamation of degraded areas are involved in the following processes: chemo-phytostabilisation (the formation of stable metal soils), immobilisation (the immobilisation of metals on the functional groups of fulvic and humic acids), phytoremediation (phytoextraction and phytostabilisation), and bio-stimulation (the addition of nutrients to stimulate the activity of soil microflora) [24, 25].

The study aimed to assess the effect of the sewage sludge from the Zakłady Azotowe Puławy biological industrial wastewater treatment plant, which has been given the status of a by-product (industrial sewage sludge), and sewage sludge from the Hajdów wastewater treatment plant (municipal sewage sludge), as components of composites with anthropogenic soil, used to form the top (0–25 cm) reclamation layer of the reclaimed sand excavation on the organic carbon and plant nutrient contents (total N and available forms of P, K and Mg).

MATERIAL AND METHODS

The study was carried out in the second year after the reclamation of the post-mining area at the Opencast Mining Facility – a sand mine operated by Kruszywa Niemce S.A. These works were carried out as part of the pilot implementation operations under the project "Optimisation of methods for drilling waste management" (BG/1/SOIL/2013).

Kruszywa Niemce S.A. is one of the largest producers of mineral aggregates in central and eastern Poland. The sand mine in Wólka Rokicka Kolonia (Lubelskie Voivodeship, Poland) covers an area of 55 ha. Sand extraction forms dry-soil excavation with varying depths, from several to approximately 30 m. The resulting post-mining are gradually being reclaimed as mining operations in a particular part of the mine come to an end.

The reclamation was carried out over a section of the excavation with an area of 0.5 ha and a depth of approximately 30 m (Figure 1a), in accordance with a developed technology [26]. The innovative reclamation technology involved the filling of the excavation with carboniferous excavation waste (CEW) (Figure 1b) and forming a reclamation cover using drilling waste (DW), carboniferous excavation waste (CEW), municipal sewage sludge from Lublin (MSS) or industrial sewage sludge that has been granted the status of a by-product, from the biological wastewater treatment plant of the Zakłady Azotowe Puławy (ISS), and anthropogenic soil (AS) originating from the foreground of the Sand Mine. The waste used in the shaping of the reclamation cover exhibited varied properties that are presented in detail in a previous study [27].

To create a technogenic soil, corresponding to good and very good soils in terms of quality, the wastes were mixed in different proportions, taking into account their chemical, physico-chemical and physical properties and the forest direction of the target management. Figure 2 shows a cross-section of the formed technogenic soil profile. In the profile of the outer reclamation layer with a depth of 1.5 m, six layers with a thickness of 25 cm each were made. These layers differed in the composition and proportion of the waste under study. The proportion of the waste used on the two layers was identical, with the only difference being the type of sewage sludge used: MSS and ISS. A detailed description of the reclamation

a) b) c)

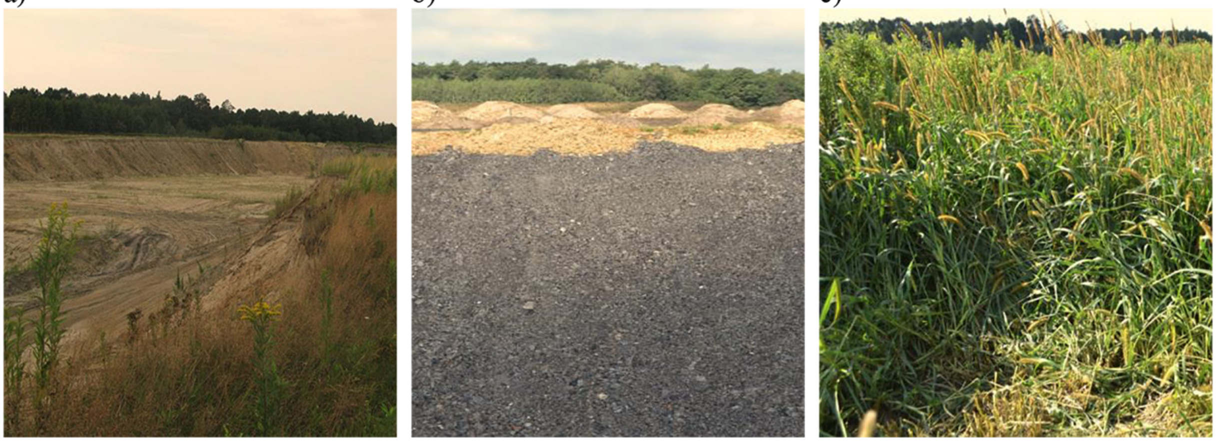

Figure 1. Reclaimed area: a) before reclamation, b) excavation filled with mining waste, c) after biological reclamation

Area A (0.25 ha) used materials	Profile cross-section (cm)	Area B (0.25 ha) used materials
AS:ISS – 10:1	0 – 25	AS:MSS – 10:1
AS:DW:DW:ISS – 5:5:1:1	25 – 50	AS:DW:DW:MSS – 5:5:1:1
AS:CEW:DW:ISS – 5:15:3:1	50 – 75	AS:CEW:DW:MSS – 5:15:3:1
AS:CEW:DW – 1:6,7:1	75 – 100	AS:CEW:DW – 1:6,7:1
CEW:DW – 5:1	100 – 150	CEW:DW – 5:1
CEW	>150	CEW

Figure 2. Cross-section of the profile of technogenic soil on a reclaimed sand excavation

works is provided in a patent [26] and a study by Bik-Małodzińska et al. [27].

In line with the Area Development Plan, forest management was designed as the target direction for the reclamation. Such a solution increases the effectiveness of reclamation using woody plants, which was observed during the reclamation and management of an area degraded by sulphur borehole mining in Jeziórko near Tarnobrzeg [28, 29]. To increase the effectiveness of forestation, the introduction of pioneer vegetation, namely a mixture of grasses, for a period of 3–5 years was included in the project. Once technogenic soil was formed, mineral fertilisation was applied on both surfaces at rates of N80P80K120 ($kg{\cdot}ha^{-1}$), and a mixture of grasses comprising *Phleum pratense* L. (20%), *Festuca ptatensis Huds (20%), Festuca rubra* L. (20%), *Poa pratensis* L. (15%) and *Dactylis glomerata* L. (20%) as well as *Trifolium pratense* L. (5%) in the amount of 80 $kg{\cdot}ha^{-1}$ were sown.

The reclaimed site was monitored over the following two growing seasons (Figure 1c). Soil samples were taken from the 0-25 cm layer for laboratory testing to assess the effectiveness of the reclamation performed. The samples were collected from five sampling sites distributed evenly over each reclaimed area. The reference point was soil samples collected from anthropogenic soil (outside the implementation area), fertilised with NPK, fertilised with manure at 30 $Mg{\cdot}ha^{-1}$ + NPK (Table 1).

In the soil samples, the following were determined:

- total organic carbon content (TOC), using a TOC-V_{CSH}, SSM-5000A Shimadzu apparatus [30],
- the total nitrogen content by the Kjeldahl method, using a Kjeltech™ 8100 distillation unit [31], and the C/N ratio was calculated,
- the contents of available forms of P and K [32],
- the available Mg content by the Schachtschabel method [33].

Table 1. Characteristics of research points

Research point	Reclamation variant
AS_I	Anthropogenic soil + NPK (control I)
AS_II	Anthropogenic soil + manure + NPK (control II)
AS_AS_ISS	Anthropogenic soil with industrial sewage sludge
AS_AS_MSS	Anthropogenic soil with municipal sewage sludge

RESULTS AND DISCUSSION

Devastated areas devoid of a soil cover require measures aimed at producing the so-called artificial soil, also referred to as constructed Technosol [34]. The restoration of the soil by technical methods (construction of Technosol) involves several stages, with the basis being the adopted target management method. To restore the soil, a mineral substrate, which constitutes the main mass of Technosol, is required [35-37]. The mineral substrate needs to be supplemented with materials that optimise the substrate's physical, chemical, physico-chemical, chemical and biological properties. The selection of supplementary materials and substrates, or their combination, and the order in which they are placed in the soil profile being constructed should result in an arrangement similar to that of the levels found in natural soils [38]. Waste materials are increasingly used in soil reclamation, especially when constructing Technosols. The use of waste in reclamation works has added value, as it reduces the amount of landfill waste, and the recovery of components important for plant nutrition is in line with the assumptions of a circular economy [39].

The study used anthropogenic soil (overburden was removed from the surface on which sand extraction was carried out) and sewage sludge to form the surface layer of the constructed Technosol. The abundance of nutrients (nitrogen, phosphorus, calcium and magnesium) and organic matter in sewage sludge prompts the utilisation of its fertilising potential, especially given the scarcity of organic substances in the substrate. Sewage sludge contributes to an improvement in the balance of organic matter in the soil and, in addition, is a source of plant nutrients [40-44].

The total organic carbon content (TOC) in the soil is a sensitive indicator of soil health and reclamation effectiveness [45, 46]. The results obtained showed that the TOC content of the anthropogenic soil fertilised with NPK was very low (6.51 $g{\cdot}kg^{-1}$). In contrast, in control soil II (anthropogenic soil + 30 $Mg{\cdot}ha^{-1}$ d.m. manure + NPK), it increased by approximately 1.2 $g{\cdot}kg^{-1}$ (Table 2, Figure 3).

In the top reclamation layer (anthropogenic soil + sewage sludge at a ratio of 10:1), the TOC content increased by 492-588% compared to the soil fertilised with NPK, and by 413-495% compared to the soil fertilised with manure (Table 2, Figure 2). The resulting organic carbon contents

Table 2. Average TOC and TN content in the reclaimed soil compared to the control objects

Research point	TOC			TN		
	$g \cdot kg^{-1}$	% to control		$g \cdot kg^{-1}$	% to control	
AS_I	6.51	100		0.88	100	
AS_II	7.74	119	100	0.96	108	100
AS_ISS	32.00	492	413	1.89	215	197
AS_MSS	38.30	588	495	2.38	270	248

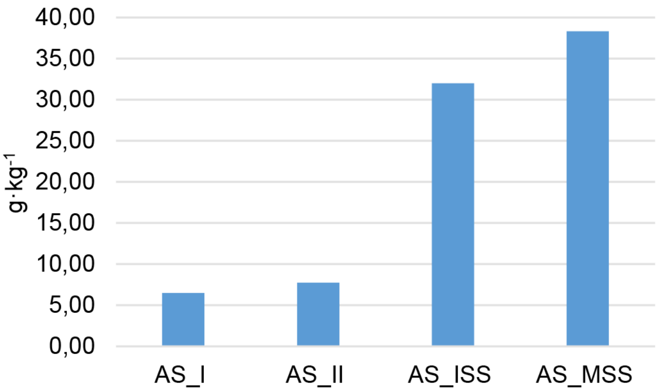

Figure 3. Influence of reclamation methods on TOC content. Average values: AS_I – anthropogenic soil + NPK (control I), AS_II – anthropogenic soil + manure + NPK (control II), AS_ISS – anthropogenic soil with industrial sewage sludge, AS_MSS – anthropogenic soil with municipal sewage sludge

of the technogenic soil corresponded to a very good quality soil. The MSS from Lublin had a more favourable (by 26%) effect on the TOC content in the reclaimed anthropogenic soil (38.3 $g \cdot kg^{-1}$) compared to this soil with the addition of the ISS from ZA Puławy (32 $g \cdot kg^{-1}$). A study by Rosa et al. [41] confirmed that sewage sludge used as a source of organic matter improves the quality of degraded soils. Siuta [47] also emphasises that sewage sludge from urban wastewater treatment is abundant in colloidal organic matter and nutrients essential to soil organisms and plants. The soil- and yield-forming potential of sewage sludge is similar to that of soil humus.

Sewage sludge is a valuable source of nitrogen. Nitrogen is a component of all proteins and nucleic acids and an essential plant element. The total nitrogen content in sewage sludge is approximately 40-50 $kg \cdot Mg^{-1}$, but only a small proportion is immediately available to plants [48]. As a result of sewage sludge mineralisation, nitrogen is converted into a available form. The total nitrogen (TN) content in the 0–25 cm layer, formed from anthropogenic soil with the addition of sewage sludge, increased by 215–270% compared to the soil fertilised with NPK, and by 197–248% compared to the soil fertilised with manure (Table 2, Figure 4). The resulting TN contents of the reclaimed anthropogenic soil corresponded to a natural soil of very good quality. The MSS had a more favourable effect (by 25%) on the total nitrogen content in the reclaimed anthropogenic soil (2.38 $g \cdot kg^{-1}$) compared to the soil with the addition of the ISS (1.89 $g \cdot kg^{-1}$). Żukowska et al. [22] and Napora and Grobelak [43] confirmed an increase in nitrogen content due to sewage sludge addition to degraded soils.

The literature draws attention to changes in the C/N ratio in reclaimed soils. Sewage sludge, due to the organic matter mineralisation processes taking place, is referred to as a fertiliser with a slow and gradual release of nitrogen, and the application of sewage sludge improves the sorption properties of the soil [20, 49].

The C/N ratio in the anthropogenic soil reclaimed using sewage sludge was wider by 8, compared to the control anthropogenic soil (Table 2). This shows that carbon and nitrogen management is unstable, and the soil-forming process is in the initiation phase.

Using sewage sludge in reclamation processes contributes to the possibility of recovering valuable elements, such as nitrogen, phosphorus, and other nutrients important to plant growth [25]. Applying sewage sludge to anthropogenic soil had a favourable effect on the contents of

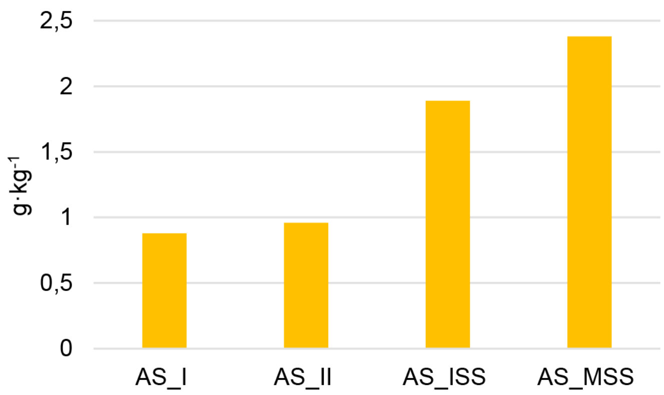

Figure 4. Influence of reclamation methods on TN content. Average values:AS_I – anthropogenic soil + NPK (control I), AS_II – anthropogenic soil + manure + NPK (control II), AS_ISS – anthropogenic soil with industrial sewage sludge, AS_MSS – anthropogenic soil with municipal sewage sludge

available forms of P, K and Mg in the technogenic soil being formed (Table 3).

Phosphorus is an essential element for numerous metabolic reactions in plants. The addition of sewage sludge to agricultural soil increases the phosphorus content from 2–4 mg·kg^{-1} to 114 mg·kg^{-1}, and its accumulation remains significant in deeper soil layers [40]. The available phosphorus content in the anthropogenic soil with the addition of the ISS increased by 3183% compared to the anthropogenic soil fertilised with NPK, and by 2640% compared to the soil fertilised with manure (Table 3, Figure 5).

These relationships for the MSS in the soil were as follows 3386 and 2809%, respectively. The effect of the MSS on the available phosphorus content in the anthropogenic soil was greater by 6% compared to that of the ISS, and amounted to 704.1 mg·kg^{-1}. A study by Siddigue and Robinson [50] demonstrated a similar effect of sewage sludge

Table 3. Average content of available components P, K and Mg in the reclaimed anthropogenic soil compared to the controls

Research point	P available			K available			Mg available		
	mg·kg^{-1}	% to control		mg·kg^{-1}	% to control		mg·kg^{-1}	% to control	
AS_I	20.2	100		27.1	100		42.6	100	
AS_II	24.2	120	100	31.2	115	100	46.5	109	100
AS_ISS	663.1	3283	2740	843.7	3113	2794	150.1	352	323
AS_MSS	704.1	3486	2909	330.2	1218	1058	336.0	789	722

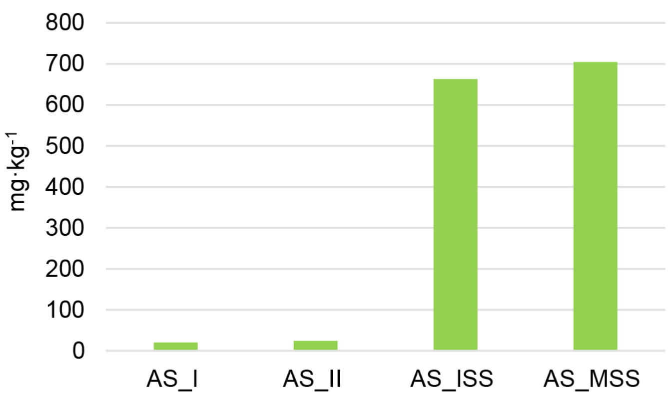

Figure 5. Influence of reclamation methods on available P content. Average values: AS_I – anthropogenic soil + NPK (control I), AS_II – anthropogenic soil + manure + NPK (control II), AS_ISS – anthropogenic soil with industrial sewage sludge, AS_MSS – anthropogenic soil with municipal sewage sludge

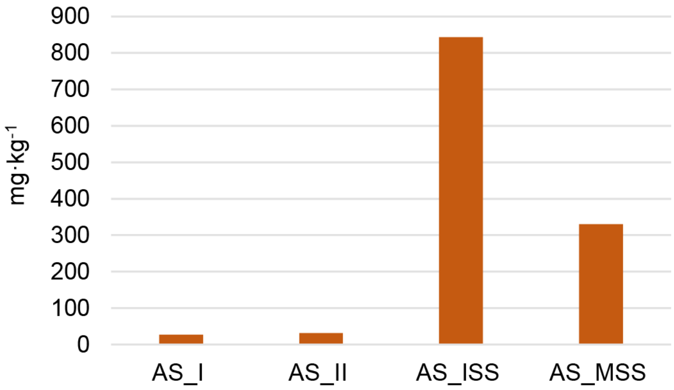

Figure 6. Influence of reclamation methods on available K content. Average values: AS_I – anthropogenic soil + NPK (control I), AS_II – anthropogenic soil + manure + NPK (control II), AS_ISS – anthropogenic soil with industrial sewage sludge, AS_MSS – anthropogenic soil with municipal sewage sludge

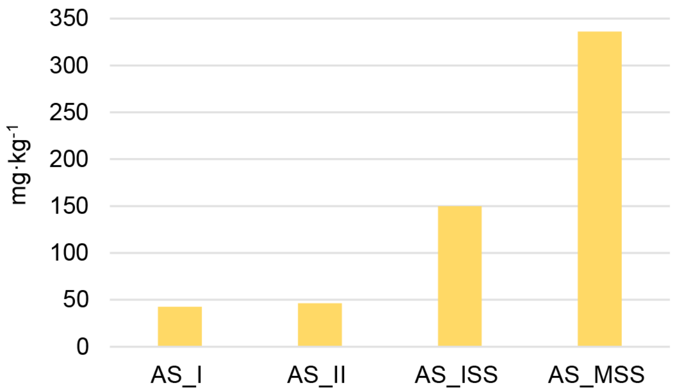

Figure 7. Influence of reclamation methods on available Mg content. Average values: AS_I – anthropogenic soil + NPK (control I), AS_II – anthropogenic soil + manure + NPK (control II), AS_ISS – anthropogenic soil with industrial sewage sludge, AS_MSS – anthropogenic soil with municipal sewage sludge

on the phosphorus content. Shober and Sims [51] noted that the increase in available phosphorus in soils fertilised with sewage sludge should be linked to the high content of this element in sewage sludge and the organic substance mineralisation process.

The available potassium content of the anthropogenic soil reclaimed using the ISS increased by 3013% compared to the anthropogenic soil fertilised with NPK, and by 2694% compared to the soil fertilised with manure (Figure 6). These relationships for the MSS were as follows 1118% and 958%, respectively. The effect of the MSS on the available potassium content of the anthropogenic soil was lower by 60% compared to the ISS. The distribution of the content of this element in the reclaimed soil is the inverse of its content in sewage sludge (Table 3), indicating that the municipal sewage sludge reduced the solubility of this element. A study by De Melo et al. [16] also demonstrated a proportional relationship between the sewage sludge application rate and the increase in soil potassium content.

The available magnesium content of the soil reclaimed using the ISS increased by 252% compared to the anthropogenic soil fertilised with NPK (the Mg content of the soil was 0.88 $mg \cdot kg^{-1}$) and by 223% compared to the soil fertilised with manure (Table 3, Figure 7).

These relationships for the MSS were as follows 689% and 622%, respectively. The effect of the municipal sewage sludge from Lublin on the available magnesium content of the anthropogenic soil was greater by 124% compared to the ISS.

CONCLUSIONS

The technology applied for the reclamation of the excavation after sand exploitation, which used waste to fill the excavation and produce Technosol by technical methods, proved to be the optimal solution in line with the assumptions of sustainable development and circular economy. An assessment of the effects of reclamation of the excavation after sand exploitation using waste material showed that the reclamation cover produced from waste material that met the ecological safety criteria provided a good substrate for the technogenic soil being formed. The composite formed from anthropogenic soil with the addition of sewage sludge (10:1) was characterised by higher contents of organic carbon, total nitrogen and bioavailable forms of P, K and Mg compared to the anthropogenic soil fertilised with NPK and manure.

In the top reclamation layer, the TOC content increased by 492–588% compared to the soil fertilised with NPK, and by 413–495% compared to the soil fertilised with manure. The MMS had a more favourable (by 26%) effect on the organic carbon content of the reclaimed anthropogenic soil compared to the ISS. The TN content increased in the 0–25 cm layer by 215–270% compared to the soil fertilised with NPK, and by 197–248% compared to the soil fertilised with manure. The observed TN contents of the reclaimed anthropogenic soil were rated as very good quality soil. The available phosphorus content of the anthropogenic soil reclaimed using the ISS increased by 3183% compared to the anthropogenic soil fertilised with NPK and by 2640% compared to the soil fertilised with manure. As regards the addition of MSS, the following relationships were found: 3386 and 2809%, respectively. The available potassium content of the anthropogenic soil reclaimed using the ISS increased by 3013% compared to the anthropogenic soil fertilised with NPK, and by 2694% compared to the soil fertilised with manure, whereas the effect of the MSS was 60% lower. The available potassium content of the anthropogenic soil reclaimed using the ISS increased by 252% compared to the anthropogenic soil fertilised with NPK (the Mg content of the soil was 0.88 $mg \cdot kg^{-1}$) and by 223% compared to the soil fertilised with manure. In contrast, the effect of the MSS was 124% greater.

Monitoring of the surface layer properties (0-20 cm), carried out two years after introducing vegetation to the reclaimed area, showed that the assessed technology of reclamation of the excavation after sand mining using waste is a good way to solve the problem of dry areas devastated by open-cast mining of mineral deposits. At the same time, such waste management is consistent with the circular economy strategy. At the same time, such waste management is in line with the strategy of the Circular Economy.

REFERENCES

1. Van Camp G., Gentile A., Bujarrabal B., Jones R., Montanarella L., Olazabal C., Selvaradjou S.. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. Monitoring. 2004.
2. Myszura-Dymek M, Żukowska G. The Influence of Sewage Sludge Composts on the Enzymatic Activity of Reclaimed Post-Mining Soil. Sustainability. 2023, 15(6), 4749. https://doi.org/10.3390/su15064749.
3. Woś B., Pietrzykowski M. The influence of tree species on the content of macroelements and properties of initial soils in the conditions of a reclaimed sand pit. Sylwan. 2019, 163(05), 407-414. DOI 10.26202/sylwan.2018151.
4. Pietrzykowski M., Krzaklewski W. Soil organic matter, C and N accumulation during natural succession and reclamation in an opencast sand quarry (southern Poland). Archives of Agronomy and Soil Science, 2007, 53(5) 473−483. https://doi.org/10.1080/03650340701362516.
5. Lapčík V., Lapčíková M. Environmental Impact Assessment of Surface Mining. Inżynieria Mineralna. 2011, 12(1), 1-10.
6. Act of 3 February 1995 on the protection of agricultural and forest land. Journal of Laws 2024.82.
7. Karczewska A., Soil protection and reclamation of degraded areas. University of Life Sciences Publishing House. 2012.
8. Topay M., Kaya L.G. The Education of Landscaping in Turkey, (in Turkish), Proc. Cong. On Landscaping Architecture, Antalya. 2007, 554-557.
9. Hall S.L., Barton C.D., Baskin C.C. Topsoil seed bank of an oak-hickory forest in eastern Kentucky as a restoration tool on surface mines. Restoration Ecology. 2009, 18(6), 834-842. https://doi.org/10.1111/j.1526- 100x.2008.00509.x.
10. Seifullina A., Er A., Nadeem S.P., Garza-Reyes J.A., Kumar V. A Lean Implementation Framework for the Mining Industry,IFAC-PapersOnLine. 2018, 51(11), 1149-1154. https://doi.org/10.1016/j.ifacol.2018.08.435.
11. Paulo J.C. Favas, Louis E. Martino, Majeti N.V. Prasad. Chapter 1 - Abandoned Mine Land Reclamation—Challenges and Opportunities (Holistic Approach), Editor(s): Majeti Narasimha Vara Prasad, Paulo Jorge de Campos Favas, Subodh Kumar Maiti, Bio-Geotechnologies for Mine Site Rehabilitation. 2018, 3-31. https://doi.org/10.1016/

B978-0-12-812986-9.00001-4.

12. Regulation of the Minister of the Environment of 11 May 2015 on the recovery of waste outside installations and devices. Journal of Laws 2015 item 796.
13. Announcement of the Speaker of the Sejm of the Republic of Poland of 27 November 2014 on the announcement of the uniform text of the act on preventing environmental damage and its remediation. Journal of Laws 2014 item 1789.
14. Larney F., Angers D.A. The role of organic amendments in soil reclamation: A review. Canadian Journal of Soil Science. 2012, 92, 19 - 38. https://doi.org/10.4141/cjss2010-064.
15. Dulewski J., Uzarowicz R. Legal aspects of reclamation and revitalization of areas degraded by mining activities. CBiDGP i IETU. 2007, 76-85.
16. De – Melo W.J., Marques M.O., De – Ferreira M.E., Melo G.M.P., De – Melo V.P. Chemical properties and enzyme activity in a sewage sludge treated soil. Communications in Soil Science and Plant Analysis. 2002, 33, 1643-1659. https://doi.org/10.1081/CSS-120004305.
17. Domene X., Mattana S., Ramírez W., Colón J., Jiménez P., Balanyà T., Alcañiz J.M., Bonmatí M. Bioassays prove the suitability of mining debris mixed with sewage sludge for land reclamation purposes. Journal of Soils and Sediments. 2010, 10, 30-44. https://doi.org/10.1007/s11368-009-0073-1.
18. Jezierska-Tys S., Frąc M., Study on the influence of sludge from a dairy sewage treatment plant on the microbiological and biochemical activity of soil. Papers and monographs, Acta Agrophysica. 2008, 3, 14-25.
19. Sullivan T.S., Stromberger M.E., Paschke M.W., Ippolito J.A., Long-term impacts of infrequent biosolids applications on chemical and microbial properties of semi-arid rangeland soil. Biology and Fertility of Soils. 2005. 42, 3, 258-266. https://doi.org/10.1007/s00374-005-0023-z.
20. Nowak M., Kacprzak M., Grobelak A. Sewage sludge as a soil substitute in the processes of remediation and reclamation of areas contaminated with heavy metals. Engineering and Environmental Protection. 2010, 13(2), 121–131.
21. Wydro U., Wołejko E., Jabłońska-Trypuć A., Butarewicz A., Łoboda T. The influence of sewage sludge on biological activity of soils. Construction and Environmental Engineering. 2017, 8(2), 103-108.
22. Żukowska G., Flis-Bujak M., Baran S. The influence of sewage sludge fertilization on the organic matter of light soil for wicker cultivation. Acta Agrophysica, 2002, 73, 357–367.
23. Zhao X.L., Mu Z.J., Cao C.M., Wang D.Y. Growth and Heavy-Metal Uptake by Lettuce Grown in Soils Applied with Sewage Sludge Compost. Communications in Soil Science and Plant Analysis. 2012, 43(11), 1532–1541. https://doi.org/10.1080/00103624.2012.675390.
24. Park J.H., Lamb D., Paneerselvam P., Choppala G., Bolan N., Chung J.W. Role of organic amendmends on enhanced bioremediation of heavy metal(loid) contaminated soils. J. Haz. Mater. 2011, 185, 549–574. https://doi.org/10.1016/j.jhazmat.2010.09.082.
25. Kacprzak M., Grobelak A., Grosser A. Prasad MNV. Efficacay of Biosolids in Assisted Phytostabilization of Metalliferous Acidic Sandy Soils with Five Grass Species. Int. J. Phytoremediation. 2014, 16(6), 593–608. https://doi.org/10.1080/15226514.2013.798625.
26. Pawłwski A., Pawłowski L., Pawłowska M., Kujawska J., Cel W., Baran S., Wesołowski M., Żukowska G., Bik-Małodzińska M., Kwiatkowski Z., 2017. Method of reclaiming mine excavations. In: European patent specification; EP 2979768 B1.
27. Bik-Małodzińska M., Żukowska G., Paśmionka I. Innovative Technologies for the Use of Drilling Waste in Reclamation and Shaping the Physicochemical Properties of Degraded Soils. Advances in Science and Technology Research Journal. 2023, 17(3), 294-301. https://doi.org/10.12913/22998624/166759.
28. Baran S., Wójcikowska-Kapusta A., Żukowska G. The influence of sewage sludge and Grodan mineral wool used for the remediation of highly acidic soils on the content of lead and nickel forms Zesz. Prob. Post. Nauk Rol. 2009, 535, 23-31.
29. Żukowska G., Myszura-Dymek M., Roszkowski S., Bik-Małodzińska M. Effect of Coal Mining Waste and Its Mixtures with Sewage Sludge and Mineral Wool on Selected Properties of Degraded Anthropogenic Soil. Journal of Ecological Engineering. 2023, 24(10), 340-350. https://doi.org/10.12911/22998993/170949.
30. PN-EN 15936:2013:02. Available online: https://sklep.pkn.pl/pn-en-15936-2013-02p.html (accessed on 20 August 2024).
31. International Organization for Standardization. Soil Quality. In Determination of Total Nitrogen Content by Dry Combustion; International Organization for Standardization: Geneva, Switzerland, 1998.
32. Polish Committee for Standardization. Polish Standard: The Chemical and Agricultural Analysis of the Soil—Determination of the Content of Assailable Phosphorus in Mineral Soils; Polish Committee for Standardization: Warsaw, Poland. 1996.
33. Schlichting E., Blume H.P., Stahr K. Bodenkundliches Praktikum. Pareys Studientexte 81. Berlin: Blackwell Wissenschafts-Verlag. 1995.
34. Naeth M.A., Archibald H.A., Nemirsky C.L., Leskiw L.A., Brierley J.A., Bock M.D., VandenBygaart A.J. Chanasyk D.S. Proposed classification for human modified soils in Canada: Anthroposolic

order. Can. J. Soil Sci., 2012, 92, 7–18. https://doi.org/10.4141/cjss2011-028.

35. Firpo B.A., do Amaral Filho J.R., Schneider I.A.H. A brief procedure to fabricate soils from coal mine wastes based on mineral processing, agricultural, and environmental concepts. Miner. Eng. 2015, 76, 81–86. https://doi.org/10.1016/j.mineng.2014.11.005.
36. Amaral L.F., Delaqua G.C.G., Nicolite M., Marvila M.T., de Azevedo A.R., Alexandre J., Monteiro S.N. Eco-friendly mortars with addition of ornamental stone waste-A mathematical model approach for granulometric optimization. J. Clean. Prod. 2020, 248, 119283. https://doi.org/10.1016/j.jclepro.2019.119283.
37. Weiler J., Firpo B.A., Schneider I.A.H. Technosol as an integrated management tool for turning urban and coal mining waste into a resource. Miner. Eng. 2020, 147, 106179. https://doi.org/10.1016/j.mineng.2019.106179.
38. Gann G.D., McDonald T., Walder B., Aronson J., Nelson C.R., Jonson J., Hallett J.G., Eisenberg C., Guariguata M.R., Liu J., Hua F., Echeverría C., Gonzales E., Shaw N., Decleer K., Dixon K.W. International principles and standards for the practice of ecological restoration. Second edition. Restor Ecol. 2019, 27, 1-46. https://doi.org/10.1111/rec.13035.
39. Żukowska G., Myszura-Dymek M., Roszkowski S., Olkiewicz M. Selected Properties of Soil-like Substrates Made from Mine Coal Waste and Their Effect on Plant Yields. Sustainability. 2023, 15, 13341. https://doi.org/10.3390/su151813341.
40. Nyamangara J., Mzezewa J. Effect of long-term application of sewage sludge to a grazed grass pasture on organic carbon and nutrients of a clay soil in Zimbabwe. Nutr. Cycl. Agroecosys. 2001, 59, 13–18. https://doi.org/10.1023/A:1009811618018.
41. Ros M., Hernandez M.T., Garcia C. Bioremediation of soil degraded by sewage sludge: effects on soil properties and erosion losses. Environmental Management. 2003, 31, 6, 741-747. https://doi.org/10.1007/s00267-002-2839-8.
42. Mtshali J.S., Tirunech A.T., Fadiran A.O. Characterization of sewage sludge generated from waste water treatment plants in Swaziland in relation to agricultural uses. Resour. Environ. 2014, 4 (4), 190–199. doi:10.5923/j.re.20140404.02.
43. Napora A., Grobelak A. The influence of sewage sludge on soil microbiological and biochemical activity. Engineering and Environmental Protection, 2014, 17(4), 619–630.
44. Tymchuk I., Malovanyy M., Bota O., Shkvirko O., Popovych O. Biological Reclamation Using a Sewage Sludge-Based Substrate – A Way to Ensure Sustainable Development of Urban Areas. Ecological Engineering & Environmental Technology. 2022, 23(1), 34-41. doi:10.12912/27197050/143029.
45. Bodlák L., Křováková K., Kobesová M., Brom J., Šťastný J., Pecharová E. SOC content—An appropriate tool for evaluating the soil quality in a reclaimed post-mining landscape. Ecological Engineering. 2012, 43, 53–59. https://doi.org/10.1016/j.ecoleng.2011.07.013.
46. Courtney R., Harrington T.J., Byrne K.A. Indicators of soil formation in restored bauxite residues. Ecological Engineering. 2013, 58, 63–68. https://doi.org/10.1016/j.ecoleng.2013.06.022.
47. Siuta J. Remedial efficiency of sewage sludge at the soda waste landfill in Janikowo. Ecological Engineering. 2014, 36, 98-119. DOI: 10.12912/2081139X.07.
48. Pakhnenko E.P., Ermakov A.V., Ubugunov L.L. Influence of sewage sludge from sludge beds of Ulan-Ude on the soil properties and the yield and quality of potatoes. Mosc. Univ. Soil Sci. Bull. 2009, 64 (4), 175–181. https://doi.org/10.3103/S0147687409040061.
49. Królak E., Kot B., Sterniczuk K., Troć A., Zychowicz E., Powalska E. The influence of organic components on changes in the properties of reclaimed forest soils in a dry coniferous forest habitat. Forest Research Works. 2017, 78 (2), 165–170. DOI: 10.1515/frp-2017-0018.
50. Siddigue M.T., Robinson J.S. Phosphorus sorption and availability in soils amendet with amimal manure and sewage sludge. Journal of Environmental Quality. 2003, 32, 1141-1121. https://doi.org/10.2134/jeq2003.1114.
51. Shober A.L., Sims J.T. Phosphorus restrictions for land application of biosolids. Journal of Environmental Quality. 2003, 32, 1955-1964. https://doi.org/10.2134/jeq2003.1955.