Possibility of forming artificial soil based on drilling waste and sewage sludge

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Abstract. Land redevelopment is necessary due to the amount of a degraded area. Depositing waste on the small area of landfills is harmful for the environment. New methods of managing and utilizing waste are being sought in order to minimize the deposition of waste. In small amounts, many types of waste can be treated as a substrate or material improving physicochemical properties of soils, and hence can be used in reclamation of degraded lands. The study analysed the effect of different doses of sewage sludge (35%, 17.5%) with addition (2.5% and 5%) of drilling waste on the properties of degraded soils. The results show that created mixtures improve the sorption properties of soil. The mixtures contain the optimal the ratio of nutrient elements for growth of plants is N:P:K.

1. Introduction

Extraction and exploitation of minerals leads to forming extensive areas of completely degraded surface. According to the Institute of Environmental Protection and the Institute of Ecology of Industrial Areas, in Poland there are over 800,000 hectares of degraded land and 3950,000 hectares of the area threatened by industrial degradation [1]. In keeping with the idea of sustainable development, these sites should be redeveloped and reused. Reclamation of such areas becomes an urgent necessity [2].

Covering these areas with waste mixtures that will allow the production of vegetation is a simple solution to protect them. The idea of mixing rock crumbs with organic waste such as animal excrements, compost or sewage sludge to create a reclamation layer on degraded land was first used in 1977 by Laga. Haraldsen created a mixture of rock crumbs, sand and various organic waste: sewage sludge and compost. It was observed that the type and amount of organic matter had a significant effect on plant growth. A mixture with sewage sludge proved the best mixture for plant growth [3].

An increasing amount of unconventional and conventional hydrocarbon exploration generates large quantities of drilling waste. The mineralogical composition of drilling waste is similar to that of soil. Their physical and chemical properties indicate that they can be used for soil reclamation, especially the sandy ones. The use of this type of waste on degraded soils can improve soil properties, increase plant yield and optimize its biogenic components.

The purpose of this article is to use drilling waste to produce the waste component that would have the properties of a soil improvement agent. We propose using sludge to achieve this goal. The resulting mixture of drilling waste and sewage sludge would constitute a biologically active layer that could be used to recreate degraded soil.
Sewage sludge and drilling waste mixed together in appropriate proportions may contribute to improving the quality of physically or chemically degraded areas. The porosity, layout and water-air conditions of soil can be improved by increasing the level of organic matter. Increasing the pH value may lead to adsorption, complexation and precipitation of heavy metals, which will subsequently limit their mobility in groundwater and bioavailability for plants. The use of waste components instead of individual waste is much more advantageous because of the ability to adjust the composition and properties of a soil improvement agent.

2. Materials and Methods
The following components were used in the mixture:

- soil material was extracted from the field situated in Felin, near Lublin (Eastern Poland)
- granulated sewage sludge coming from the Hajdów Sewage Farm in Lublin
- drill cuttings that were taken from facility of mining waste in Luchow

The scope and analytical methods of determination of physical and chemical parameters of mixtures and their components:

- dry matter content by means of loss on drying method in the temperature of 105°C (PN EN ISO 11465:1999P soil quality. Determination of dry matter content of soil and water in soil per dry mass of soil. Gravimetric method),
- pH value by means of potentiometric method in water solution and in 1 M solution of potassium chloride (PN-ISO 10390: 1997P soil quality. Determination of pH),
- specific gravity (ρs), Le Chatelier flask method, in the temperature of 22°C,
- granulometric composition sieve analysis (PN-EN ISO 14688-2:2006),
- bulk density (ρb), Kopecky’s cylinder method with standard volume of 100 mL,
- total porosity (n) was calculated on the basis of actual density and volumetric density, according to the following equation:

\[ n = \frac{\rho_s - 9S}{\rho_s} \times 100\% \]

- hydrolytic acidity (Kh) by Kappena method, in 0.5 mol/dm³ (CH₃COO)₂Ca,
- total exchangeable bases (S) by Pallmann method in 0.5 mol/dm³ NH₄Cl at pH 8.2,
- cation exchange capacity (T) as a sum of S and Kh,
- carbonate content was determined with Scheibler’s volumetric method,
- total organic carbon by means of TOC-5050A analyzer Schimadzu (PN-ISO 4335 standard),
- total nitrogen content by Kjeldhal method using 1002 Kjeltech distillation unit
- total phosphorous and heavy metals were determined by ICP-OES Ultrace 238 (Jobin Yvon-Horriba France) using direct calibration method after microwave digestion (Multiwave 3000, Anton Paar). The samples of homogenized soil (1 g) were digested in acid mixture of HNO₃: HCl (5:2) and water samples (15 g) were digested in HNO₃ (3 mL). The digestion process lasted 45 min at 180°C and at the pressure of 18 bars. Metal concentrations were determined at different wavelengths (213–395 nm). Detection limits for particular metals did not exceed 10 ppb.

3. Mixture composition
Granulated sewage sludge was obtained from Hajdów Sewage Farm in Lublin. The content of Cd, Cr, Cu, Pb, Zn and Ni in sediments is shown in Table 1. The concentration of metals is low and does not exceed the limits for the agricultural use of sewage sludge specified in the Regulation of the Polish Minister of Environment on Municipal Sewage Sludge (Journal of Laws, 2015, item 257) [4]. The drill cuttings were extracted from the waste layer deposited at a waste disposal facility in Luchow. They are strongly alkaline (pH 11). As indicated in Table 2, the concentrations of metals in drill cuttings did not exceed the limit values given in the Regulation of the Polish Minister of Environment on the Quality of Soil Quality Standards (Journal of Laws, 2016, item 1359) with the exception of barium [5].
Table 1. Concentrations of heavy metals in sewage sludge.

| Elements | Concentration (ppm) | Limit values for concentrations of heavy metals in agriculture (ppm) [4] |
|----------|---------------------|---------------------------------------------------------------------|
| Cd       | 0.2                 | 20                                                                 |
| Cu       | 915                 | 1000                                                               |
| Ni       | 204                 | 300                                                                |
| Pb       | 119                 | 750                                                                |
| Zn       | 1770                | 2500                                                               |
| Hg       | < g.o.              | 16                                                                 |
| Cr       | < g.o.              | 500                                                                |

Table 2. Concentrations of heavy metals in drill cuttings.

| Elements | Concentration (ppm) | Permissible concentration in soils (ppm) [5] |
|----------|---------------------|-------------------------------------------|
| Ba       | 1820                | 1000                                     |
| Cd       | 0.2                 | 15                                       |
| Co       | 0.08                | 200                                      |
| Cr       | 62.63               | 500                                      |
| Cu       | 99.23               | 600                                      |
| Pb       | 27.21               | 600                                      |
| Ni       | 39.92               | 300                                      |

3.1. Composition of waste components.

A series of ternary soil-like mixtures were prepared: acidic podzol soil with the following additions of drill cuttings and sewage sludge in the proportions shown in Table 3.

Table 3. Scheme of experiment.

| Component | Composition                                      |
|-----------|-------------------------------------------------|
| Component P | Soil + 2.5% drill cuttings (v/v) + 35% sewage sludge (v/v) |
| Component R | Soil + 5% drill cuttings (v/v) + 35% sewage sludge (v/v) |
| Component M | Soil + 2.5% drill cuttings (v/v) + 17.5% sewage sludge (v/v) |
| Component O | Soil + 5% drill cuttings (v/v) + 17.5% sewage sludge (v/v) |

3.2. Statistical analysis

Mean values with standard deviation were calculated for the results of this study. Then, the statistical analyses based on the one-way analysis of variance (ANOVA) and multiple T-Tukey tests with the significance level $\alpha = 0.05$ were carried out. T-Tukey's multiple comparative tests provided a detailed comparative analysis of mean values by isolating statistically homogeneous groups (homogeneous groups). The matrix of correlation coefficients between the variables was determined. The calculations were made using the Statistica 13.0 (the license of the Faculty of Environmental Engineering, Lublin University of Technology).

4. Results and discussion.

Table 4 shows the properties of ternary mixtures which may have a significant influence on the direction and intensity of the processes occurring in soils.

The addition of the waste component increased the fraction of sand in the created mixtures. All the mixtures produced are characterized by a fine grain size with a prevalence of PM fraction (0.05 ÷ 0.002 mm) that accounts for over 50% of their total mass. The sand fraction (0.05 ÷ 0.002 mm) represents 30 to 50%. The dominant PM fraction increases the water holding capacity of soils. The created mixtures can be classified as sandy soils [6].
The variable composition of the added waste components did not significantly affect the bulk and actual density and porosity of the light soil. The post hoc statistical analysis using Tukey's honest significance test did not show a significant statistical effect of the waste component on the density, volume and porosity of the soil either. The density of the created mixtures is characteristic for mineral-organic soils in which this parameter ranges from 1.8 to 2.60 g/cm³. Besides, the bulk density of the mixtures was in the lower range of typical values for mineral soils, ranging from 0.75 to 1.30 g/cm³. The porosity of individual mixtures is comparable to the porosity of peat soils that amounts to 55-80% [6].

| Mixtures | Granulometric composition (%) | Specific gravity (g/cm³) | Bulk density (g/cm³) | Total porosity (%) |
|----------|-------------------------------|-------------------------|---------------------|-------------------|
|          | Sand fraction | Silt fraction | Clay fraction |          |                      |                      |                      |                      |
| Soil     | 23 | 71 | 6 | 2.57 ± 0.02 | 1.14 ± 0.01 | 55.45 |
| P        | 45 | 50 | 5 | 2.48 ± 0.01 | 0.91 ± 0.03 | 63.31 |
| R        | 38 | 56 | 6 | 2.47 ± 0.001 | 0.92 ± 0.01 | 62.80 |
| M        | 30 | 65 | 5 | 2.46 ± 0.002 | 1.07 ± 0.01 | 59.39 |
| O        | 31 | 64 | 5 | 2.47 ± 0.06 | 1.04 ± 0.01 | 56.64 |

The uppercase letter next to the average content values in the Table (Tukey Homogeneous Groups) indicates statistically homogeneous groups. The presence indicator designates the lack of statistically significant difference between them.

Addition of the waste component increases the dry matter content in sandy soil (Table 5). The Tukey’s test confirmed that the addition of the waste component constitutes a statistically significant increase in the organic matter content. No statistically significant differences in the organic matter content between the analysed soil mixtures P, R and M, O were observed. The resulting mixtures exhibit organic matter content similar to that of black soil, in the range of (2.22% – 46.5%) [6]. High content of organic matter and humus in soil is a stabilising component to its structure, prevents soil compaction and degradation on account of water and wind erosion. Soils of agricultural lands demonstrate 5-7% organic matter content [7], which pales into insignificance in view of the created mixtures’ organic matter content. It is precisely the said high content of the organic matter that earmarks the waste component as a perfect solution for agriculture applications [8].

Carbonate content upon soil enrichment with the waste component is marked with a tenfold increase in comparison with standard soil. This growth may be largely contributed to the presence of drill cuttings and amounts to 1% in all created soil mixtures, which corresponds with the average content of carbonate in soils of agricultural lands in Poland. Statistical analysis confirms that the addition of the waste component has had a statistically significant effect on the carbon content in all soil mixtures in question.

From the viewpoint of biochemical changes in the soil environment, there is a marked significance of the carbon to nitrogen to phosphorus ratio (C:N:P). The right proportion of these elements guarantees the proper course of changes of organic to mineral matter (mineralisation), or to humus components (humification). The optimal C:N:P ratio for soil reclamation 10:1:100, which is precisely the case with the created soil mixtures [9].

The post hoc statistical analysis conducted by means of the Tukey test showed that the addition of the waste component was statistically significant to the increase of nitrogen, carbon and phosphorus content in soil. No such difference was noted for the carbon content in the mixtures. The phosphorus content in mixture R shows statistically significant difference with the other soil mixture variants. Finally, no statistically significant differences were observed in nitrogen content in P, R and M, O soils.
The key indicator of humus content in soil is paramount to the growth, development and harvesting of plants. In biological reclamation the reaction of calcium and alkaline reaction accelerate soil mineralisation and foster plant biomass growth [10]. Similar results were obtained in the presented tests. Cutinin et al. show that the increase in the C:N content in slightly acidic soils, the elevated levels of calcium and alkaline reaction accelerate soil mineralisation and foster plant biomass growth [10].

**Table 5.** Selected chemical properties of the soils and the mixtures (±standard deviation).

| Mixtures | Carbonate content (%) | Dry matter content (%) | N (%) | C (%) | P (%) |
|----------|-----------------------|------------------------|-------|-------|-------|
| Soil     | 0.02±0.02             | 1.9±0.05               | 0.06±0.01 | 0.03±0.01 | 2.53±0.98 |
| P        | 1.87±0.29             | 23.2±0.65              | 1.61±0.02 | 13.53±1.39 | 149.66±52.68 |
| R        | 1.01±0.08             | 22.3±0.73              | 1.59±0.06 | 12.82±2.32 | 184.22±78.21 |
| M        | 1.45±0.42             | 11.7±0.07              | 0.77±0.07 | 6.32±0.73 | 110.06±56.44 |
| O        | 0.8±0.001             | 12.1±0.67              | 0.85±0.061 | 7.02±0.49 | 142.31±68.21 |

The uppercase letters a,b,c,d next to the average content values in the Table (Tukey Homogeneous Groups) indicate statistically homogeneous groups. The presence of the same indicator designates the lack of statistically significant difference between them.

The content of mineral elements smaller than 0.02 mm in soil is regarded to be the key indicator of humus content in soil. Hence, the richer the soil is in mineral elements, the higher humus content it should exhibit. Humus content in soil is calculated by multiplying the organic carbon content (Corg) by 1.7 factor. The humus content in all mixtures is higher than 3%, which is indicative of highly fertile chernozem soils (with humus content in the range of 1.2 – 4.1%) [6].

The presence of the waste component contributed to the elevated level of soil pH, hence the soil mixtures approached the neutral reaction (Table 6). The pH levels of the analysed soil material indicate their suitability for the majority of agricultural plants. In biological reclamation the reaction of the soil is paramount to the growth, development and harvesting of plants. Furthermore, it is the range of soil reactions from acidic to neutral that proves the most beneficial for the majority of plants [11].

**Table 6.** pH value of the soils and of the mixtures (±standard deviation).

| Mixtures | pH in H2O | pH in KCl |
|----------|-----------|----------|
| Soil     | 4.16±0.04 | 4.01±0.01 |
| P        | 6.41±0.08 | 6.41±0.01 |
| R        | 6.39±0.01 | 6.33±0.02 |
| M        | 6.38±0.02 | 6.47±0.04 |
| O        | 6.34±0.03 | 6.4±0.03  |

The uppercase letters a,b,c next to the average content values in the Table (Tukey Homogeneous Groups) indicate statistically homogeneous groups. The presence of the same indicator designates the lack of statistically significant difference between them.

The presence of the waste component in soil highly increases the cation exchange capacity and the total exchangeable bases in sandy soil (Figure 1). The cation exchange capacity of the mixtures is above 20 cmol(+)kg⁻¹, which is comparable to non-degraded chernozem soils. What is decisive in such high cation exchange capacity of soils is the silt and humus content and the basic reaction wastes. High cation exchange capacity is beneficial to soil as the nutritional elements in soil are stopped from leaching deeper into the soil profile and into the underground water, but are retained in the rooting...
zone of plants and released from the cation exchange complex during the plant growth periods. What is more, in soils contaminated with excessive metal content (particularly cadmium or lead) high cation exchange capacity prevents leaching and transfer of metals to the food chain [6]. The cation exchange capacity in the created soil mixtures is very high compared to soils characteristic of Poland, and may be only compared with fertile chernozem soils [15].

The soil mixtures are characterised by high values for the sum of the total exchangeable bases (S). According to IUNG data (2012), the average sum of basic cations in arable soils in Poland is approx. 8 cmol(+)/kg, and the highest recorded values amount to 40 cmol(+)/kg [16].

High basic cation content in soil is of benefit to plant growth due to the fact that exchangeable ions in the cation exchange complex transferred into the soil solution constitute an important source of minerals for plants [11].

The post hoc statistical analysis with the Tukey test showed that the addition of the waste component was statistically significant to the increase in the cation exchange capacity and the sum of the total exchangeable bases in soil.

The increase in the exchangeable ion content, observed in the study, is the effect of drilling waste on sandy soil. The sewage sludge contains negligible amounts of calcium or magnesium, and it is only by adding the drilling waste, characterised by high content of exchangeable cations, that the soil becomes enriched in those cations [11]. Other researchers enrich the sewage sludge with ash and thus prepared composition add to soil with a view to reclaiming because, similarly to drilling waste, ash are rich in exchangeable cations and may therefore be used to improve soil fertility and growth of biomass of agricultural plants [17]-[19].

5. Conclusion
The results of the research confirm the possibility of using waste mixtures, i.e., drill cuttings and sewage sludge to improve the quality of degraded soils. The mixtures contain the optimal reaction and the ratio of nutrient elements to growth of plants N: P: K. The mixtures show very good
physicochemical properties. The addition of the waste component increased the sorption capacity of the soil. The value of the sorption capacity of the created mixtures is comparable to that of Chernozem soils.

6. References

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