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EFFECT OF SEWAGE SLUDGE AND MINERAL WOOL ON WATER RETENTION AND HEAVY METAL CONTENT IN MEDIUM AGRONOMIC CATEGORY SOIL

Water retention in soil plays a key role in the context of water scarcity connected with climate change. Under the conditions of the laboratory experiment, the effect of the addition of mineral wool from crops grown under cover and municipal sewage sludge on the water retention and heavy metal (Pb, Zn, and Cd) leaching performance of the medium soil was evaluated. Sewage sludge and mineral wool, widely applied in a range of soil reclamation technologies, were found to have a beneficial and diversified impact on the soil water properties and heavy metal mobility.

1. INTRODUCTION

The researches about factors influencing water retention in soil are very important, especially in times of climate change and water scarcity. Water retention is among the key indicators of soil properties and quality [1–5]. In light sandy soils, this is an essential condition of their productivity [6]. However, the water and chemical properties of medium soils, i.e., of heavier granulometric composition, will typically require intervention [7, 8]. The aggregate structure of soils is reflected in the content of capillary pores, retention of water available for plants, and the content of macropores that condition soil water conductivity, capacity, and air permeability [9–11].

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The soil retention properties may be improved through agrotechnical treatment and fertilization with organic fertilizers or lime stabilization [12, 13]. Modification of water and chemical properties of soils may moreover involve the use of proper quality waste, thus, contributing to waste management optimization [14, 15]. As the research results have shown [16, 17], recycled Grodan mineral wool substrate from crops grown under cover and municipal sewage sludge exhibit a profound effect in improving the water properties of light soils [18, 19]. However, little is known on soils with heavier granulometric composition.

This study aimed to assess the effect of mineral wool waste from crops grown under cover and municipal sewage sludge applied in various technologies for medium soil on its water retention and mobility of Pb, Zn, and Cd.

2. MATERIALS AND METHODS

The material subjected to tests in a model laboratory experiment was medium soil (dusty sand). The municipal sewage sludge was applied to the substrate at the dose of 100 $Mg\cdot ha^{-1}$, concerning the weight of soil in the pot (0.18 kg) (Table 1). The dose of 400 $m^3\cdot ha^{-1}$ mineral wool from crops grown under cover was placed in the cylinder: it was either evenly distributed throughout the pot, or in the form of a 5-cm thick insert, placed inside at a depth of 40 cm. The control was soil without any additives.

The experiment was performed in 5×60 cm hardened PVC cylinders (Fig. 1). The pots were filled with soil with the addition of tested waste – up to a height of 50 cm, in triplicate samples. 500 cm^3 of deionized water was poured into each cylinder, and finally, the volume of filtrates was measured after 4, 8, and 24 hours.

Fig. 1. Test set-up (photo: Marta Bik-Małodzińska)

Table 1

Laboratory test samples

Number	Land reclamation variant
1	soil
2	soil + sewage sludge (100 $Mg \cdot ha^{-1}$) distributed evenly in the pot
3	soil + mineral wool (400 $m^3 \cdot ha^{-1}$) a 5-cm insert at the depth of 40 cm
4	soil + mineral wool (400 $m^3 \cdot ha^{-1}$) distributed evenly in the pot
5	soil + sewage sludge (100 $Mg \cdot ha^{-1}$) mineral wool (400 $m^3 \cdot ha^{-1}$) distributed evenly in the pot
6	soil + sewage sludge (100 $Mg \cdot ha^{-1}$) + mineral wool (400 $m^3 \cdot ha^{-1}$) a 5-cm insert at the depth of 40 cm

The soil and waste samples were tested to determine:

- the granulometric composition of soil by Casagrande-Proszynski's aerometric method,
- the potentiometric reaction in H_2O and 1 $mol \cdot dm^{-3}$ KCl,
- the hydrolytic acidity (Hh) by Kapen's method in 1 $mol \cdot dm^{-3}$ CH_3COONa,
- base cations (S) in 0.5 $mol \cdot dm^{-3}$ extract of ammonium chloride (pH 8.2) using the Pallmann method,
- the adsorption capacity (*T*) and the degree of saturation of the adsorption complex with base cations (*V*),
- the SOC mineralization (*Ct*), using a TOC analyzer and TOC-VCSH, SSM-5000A instrument,
- the heavy metal content: Pb, Zn, Cd (also in the filtrates) by the ICP-AES method using the Leeman PS 950 camera.

The results from the measurements have been subjected to statistical analysis with the use of STATISTICA 5: Anova/Manova Version, '97 Edition. The statistical analysis employed Tukey's formula for confidence interval at a significance level of 0.05.

3. RESULTS AND DISCUSSION

3.1. PROPERTIES OF MATERIALS USED IN THE EXPERIMENT

The investigated medium soil, whose granulometric composition resembled sandy dust, was slightly acidic –pH in water was 6.2 and in 1 M KCl – 6.0 (Table 2). The soil exhibited poor adsorption properties and an average carbon content, which confirms former studies, e.g., [7]. The content of heavy metals was low [20, 21].

Grodan mineral wool from horticultural crops grown under cover shows favorable adsorption properties, in particular, the high content of base cations (57.04 cmol(+) kg^{-1}), which combined with low hydrolytic acidity (3.82 cmol(+) kg^{-1}) ensures high degree base cation saturation, amounting to 93.72% (Table 2). The substrate in question has a high water retention capacity, which can prove highly beneficial considering the biological reclamation of degraded soils and devastated soil recovery [1, 19, 22].

Table 2

Selected properties of soil, mineral wool and sludge used in tests

Property	Soil	Mineral wool	Sewage sludge
Granulometric composition, % sand particles dust particles clay particles	 47 36 17	–	–
pH in H_2O	6.2	5.8–6.9	6.8
pH in 1 M KCl	6.0	5.3–6.6	6.4
Hh, cmol(+)·kg^{-1}	3.2	3.82	4.50
S, cmol(+)·kg^{-1}	5.7	57.04	50.04
T, cmol(+)·kg^{-1}	8.9	60.86	54.54
V, %	64.0	93.72	91.7
TOC, g·kg^{-1}	12.1	28.5	193.8
Zn contents, mg·kg^{-1}	20.8	133.50	935.0
Pb contents, mg·kg^{-1}	32.7	35.50	29.2
Cd contents, mg·kg^{-1}	0.17	0.50	3.45

The municipal sewage sludge was approximately neutral with pH 6.4 in 1 M KCl (Table 2), showed high adsorption capacity (54.54 cmol(+) kg^{-1}), base cations content (50.04 cmol(+) kg^{-1}) as well as high carbon content (193.8 g·kg^{-1}). The content of heavy metals was below the reference levels described in the regulation of the Minister of the Environment on municipal sewage sludge [23].

3.2. EFFECT OF MINERAL WOOL APPLICATION METHOD ON SOIL WATER RETENTION

The highest amount of filtrate (220 cm^3 – 44% of the water used) was obtained from the control soil (Table 3, Fig. 2). This confirms earlier findings by Rosik-Dulewska et al. [24], which showed that soils of a heavier granulometric composition are characterized by a greater superior retention capacity than sandy soils [25]. Compared to the pure soil, the addition of waste substrates into the soil led to the reduction in the volume of filtrate: for sewage sludge – by 25% (125 cm^3), and mineral wool in the range of 24.8–35.6% (150–178 cm^3), depending on the application method.

In soils enriched in sewage sludge and mineral wool, the volume of filtrate diminished by 68% compared to the soil containing sewage sludge alone, by 48% compared to the soil with mineral wool distributed evenly in the pot, and by 53% in soil with mineral wool insert at a depth of 40 cm. It was found that the water retention of the soil with the addition of sewage sludge and mineral wool was the highest among the reclamation methods in question. Moreover, the effect of the wool application method was largely consistent.

Table 3

The volume of filtrate and water retention of the surveyed soil reclamation variants

Soil reclamation variant	Filtrate volume [cm^3]				Water retention [cm^3]
	after 4 h	after 8 h	after 24 h	Total	
Soil	120	80	20	220	280
Soil + sewage sludge (100 Mg·ha^{-1}) distributed evenly in the pot	0	85	40	125	375
Soil + mineral wool (400 m^3·ha^{-1}) a 5-cm insert at the depth of 40 cm	0	26	124	150	350
Soil + mineral wool (400 m^3·ha^{-1}) distributed evenly in the pot	0	93	85	178	322
Soil + + sewage sludge (100 Mg·ha^{-1}) + mineral wool (400 m^3·ha^{-1}) distributed evenly in the pot	0	35	50	85	415
Soil + sewage sludge (100 Mg·ha^{-1}) + mineral wool (400 m^3·ha^{-1}) a 5-cm insert at the depth of 40 cm	0	20	60	80	420
LSD *significant differences in $p = 0.05$ ** significant differences in $p = 0.01$	according to variant 135.03** according to time 75.45*				

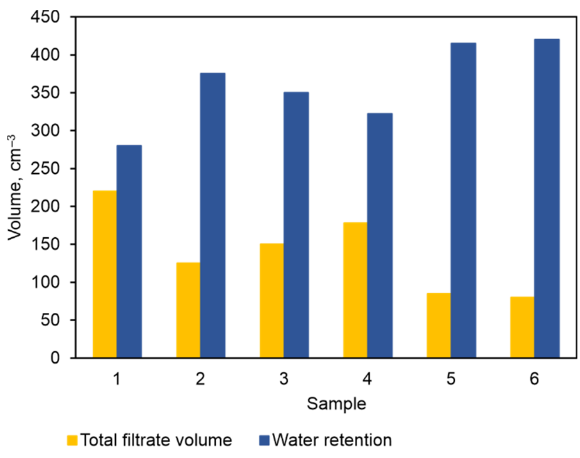

Fig. 2. Total filtration volume and water retention across soil reclamation variants: 1 – soil, 2 – Soil + sewage sludge (100 Mg·ha^{-1}) distributed evenly in the pot, 3 – soil + mineral wool (400 m^3·ha^{-1}) a 5-cm insert at the depth of 40 cm, 4 – soil + mineral wool (400 m^3·ha^{-1}) distributed evenly in the pot, 5 – soil + sewage sludge (100 mg·ha^{-1} mineral wool (400 m^3·ha^{-1}) distributed evenly in the pot), 6 – soil + sewage sludge (100 Mg·ha^{-1}) + mineral wool (400 m^3·ha^{-1}) a 5-cm insert at the depth of 40 cm

The presence of 5-cm mineral wool insert in the soil at a depth of 40 cm was shown to reduce the amount of filtrate by 32% and improve water retention by 25% compared to the results from the control soil. In the case of wool distributed evenly in the pot, the collected filtrate was lower by 19%, and the water retention increased by 15% (Table 3).

Concerning soil water retention characteristics depending on the waste enrichment variant, the investigated methods of soil reclamation compared to the control are ordered accordingly: soil + sludge + wool (150%) > soil + sludge (134%) > soil + wool (120%) > soil (100%).

Regarding the effect of the wool application method on water retention, compared to the control, the following series of results is obtained: soil + wool – insert 5 cm (125%) > soil + wool distributed evenly in the pot (115%) > soil (100%).

3.3. EFFECT OF MINERAL WOOL APPLICATION ON HEAVY METAL LEACHING FROM SOIL

The Pb content in the investigated soil was 32.70 mg·kg^{-1}, in the municipal sewage sludge 29.20 mg·kg^{-1}, and in the mineral wool 35.50 mg·kg^{-1} (Table 2). These values indicate that the amount of Pb was below the reference levels [18]. The addition of waste products to the examined soil slightly changed its total Pb content. In comparison with the control soil, the Pb content in the filtrates obtained from particular soil reclamation variants was 1.5–1.9 times higher (Table 4). The amount of Pb in the filtrates compared to the control soil amounted to 1.01%, while in the soil reclamation variants it was in the range of 1.57–1.96%.

Pb was leached most efficiently (1.96%) from the soil with the addition of sewage sludge, to a lesser extent (1.68–1.69%) from the soil with mineral wool combined with sewage sludge, whereas the soil containing mineral wool showed the smallest Pb-leaching capacity (1.55–1.57%). The method of mineral wool application was shown not to affect the leaching of Pb from the soil.

The Zn content in the soil was 20.80 mg·kg^{-1}, which qualifies as low according to the scale of reference [18]. The Zn content in sewage sludge was 935 mg·kg^{-1}, and in mineral wool 133.5 mg·kg^{-1} (Tables 2, 4), nevertheless, these values are still below the levels given in the literature [16, 18]. The application of waste to the soil was observed to increase the Zn content by 32% for the sewage sludge/mineral wool composite, by 28% in the case of sewage sludge, and 5% in mineral wool, which confirms the results from [17]. Compared to its total content in the soil, the amount of Zn in the filtrates collected from the control soil was equal to 1.55%, while in different soil the reclamation variants it was found in the range of 1.10–1.65%.

Among the reported soil reclamation variants, the highest Zn leaching rate (1.65 –1.75%) was observed in the case of the soil with mineral wool, subsequently, in the soil with the addition of sewage sludge (1.41%), and finally, the lowest efficiency was observed in the soil containing the sewage sludge/mineral wool composite (1.10%–1.15%). Mineral wool, implemented as an insert in the soil was proven to be more effective at reducing Zn leaching than when distributed evenly in the soil substrate.

Table 4

Pb, Zn and Cd content in soil, waste, and filtrates according to soil reclamation variants, $mg \cdot kg^{-1}$

Soil reclamation variant	Pb			Zn			Cd		
	Total	Filtrate	Per cent	Total	Filtrate	Per cent	Total	Filtrate	Per cent
Soil	32.70	0.331	1.01	20.80	0.322	1.55	0.17	0.008	4.68
Soil + sewage sludge (100 $Mg \cdot ha^{-1}$) distributed evenly in the pot	32.92	0.646	1.96	47.34	0.668	1.41	0.26	0.014	5.38
Soil + mineral wool (400 $m^3 \cdot ha^{-1}$) a 5-cm insert at the depth of 40 cm	32.73	0.507	1.56	21.80	0.360	1.65	0.17	0.007	4.12
Soil + mineral wool (400 $m^3 \cdot ha^{-1}$) distributed evenly in the pot	32.73	0.515	1.57	21.80	0.382	1.75	0.17	0.007	4.12
Soil + sewage sludge (100 $Mg \cdot ha^{-1}$) mineral wool (400 $m^3 \cdot ha^{-1}$) distributed evenly in the pot	32.95	0.553	1.68	48.34	0.558	1.15	0.26	0.011	4.23
Soil + sewage sludge (100 $Mg \cdot ha^{-1}$) + mineral wool (400 $m^3 \cdot ha^{-1}$) a 5-cm insert at the depth of 40 cm	32.95	0.556	1.69	48.34	0.532	1.10	0.26	0.011	4.23
LSD * significant differences in $p = 0.05$, ** significant differences in $p = 0.01$ according to variant according to metal	0.40* 0.22**			23.75 13.27**			1.34 0.75**		

Total – metal content in soil reclamation variants, Filtrate – metal content in the filtrates, Per cent – percentage of metal in the filtrate corresponding to the total content in the soil.

While the Cd content in soil (0.17 $mg \cdot kg^{-1}$) and mineral wool (0.50 $mg \cdot kg^{-1}$) was low, its level in sewage sludge was higher (3.45 $mg \cdot kg^{-1}$); nonetheless, these are below the reference levels [18] (Table 2). Sewage sludge alone, as well as in a composite with mineral wool, increased the Cd content in soil by 52%, still, the recorded values were significantly lower than permitted [18] (Table 4). These results confirm the data found in [26].

The share of Cd in the filtrates from the control soil, compared to the total content, was at the level of 4.68%, while in the filtrates from the soil reclamation variants were in the range of 4.12–5.38%.

From the examined reclamation variants, Cd was washed to the greatest extent (5.38%) from the soil with the addition of sewage sludge, to a smaller extent (4.23%) from the soil with mineral wool/sewage sludge composite, and the smallest (4.12%) from the soil with mineral wool. No effect of the mineral wool application method on the migration of Cd from the soil was observed.

4. CONCLUSIONS

- The investigated waste products show a significant but diversified impact on water retention properties of medium soil.
- The water retention of soils containing different analysed waste products can be presented in the form of a series of soil reclamation methods ordered according to their effectiveness: soil + sewage sludge + wool (150%) > soil + sewage sludge (134%) > soil + wool (120%) > soil (100%).
- The wool application variants affected water retention in soil: soil + wool – 5 cm (125%) insert > soil + wool distributed evenly in the entire pot (115%) > soil (100%).
- The addition of the examined waste to the soil had an effect on the content of heavy metals in soil and filtrates:
- The total Pb content in soils was shown to slightly change. According to the intensity of Pb leaching from the soil, the soil reclamation options are ranked as follows: soil + sewage sludge (1.96%) > soil + sewage sludge/mineral wool composite (1.68–1.69% > soil + mineral wool (1.55–1.57%).
- The sewage sludge/mineral wool composite increased the Zn content in soil by 32%, sewage sludge by 28% and mineral wool by 5%. According to Zn leaching performance, the soil reclamation variants are: soil + mineral wool (1.65–1.75%) > soil + sewage sludge (1.41%) > soil + sewage sludge/mineral wool composite (1.10–1.15%).
- The sewage sludge and sewage sludge/mineral wool composite increased the Cd content in soil by 52%. According to the Cd leaching intensity, the soil reclamation variants are ordered: soil + sewage sludge (5.38%) > soil + sewage sludge/mineral wool composite (4.23%) > soil + mineral wool (4.12%).

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