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Substrates based on composted sewage sludge for land recultivation

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Abstract. Increasing a large amounts of sewage sludge in Ukraine is an urgent environmental problem that requires the selection of an effective strategy for their disposal. The usage of sludge composting technology leads to the restoration of sludge as a resource and is cost-effective and environmentally sustainable compared to the method of landfilling. The purpose of this research is to carry out bioindication tests of growth substrates based on composted sewage sludge with the subsequent possibility of their usage in the technology of recultivation of landfills for municipal solid waste. The experiment was performed on four types of compost with different modifications of the natural sorbent – zeolite. During the experiment the average percentage of germination of polygamous ryegrass plants (*Lolium perenne* L.) was determined in the investigated substrates. The mass and length of the aboveground part of the plant and roots were also measured. The results showed that the addition of natural sorbent to substrates has a positive effect on growth and development of plants.

This investigation was conducted in accordance with the current norms of national standards of Ukraine: DSTU 7369 (2013), „Wastewater. Requirements for wastewater and its sediments for irrigation and fertilization"; DSTU ISO 11269-1 (2004), „Soil quality. Determination of the effect of pollutants on soil flora. Part 1: Method for determining the inhibitory effect on a root growth"; DSTU ISO 11269-2 (2002), „Soil quality. Determination of the effect of pollutants on soil flora. Part 2: Effects of Chemicals on Germination and Growth of Higher Plants". The experiment was conducted on four types of compost with different modifications of the natural sorbent – zeolite in percentage amounts: 0; 2.5; 5; 7.5, dark-grey gilded soil was used as a control element. In the experiment, the average percentage of germination of polygamous ryegrass plants (*Lolium perenne* L.) on the studied substrates was determined. The mass and length of the aboveground part of the plant and roots were also measured.

The first sprouts of ryegrass began to appear on the 7th day of the experiment. The highest average value on the seventh day of germination was 90% in the control sample with 5% of sorbent content and in K2 substrate in the sample with 7.5% sorbent content. However, the germination of plants in substrates K3 and K4 occurred later compared with substrates K1, K2, and control. For substrate K1 in the sample with a sorbent content of 5%, plant germination was the highest and was 100%. The highest average value of ryegrass stem length is observed in variant K4 in the sample with 0% zeolite content and in variant K1 in the sample without zeolite content the lowest average value of stem length was observed. The K3 and K4 variants have a more developed root system compared to other variants.

Based on the obtained data it can be assumed that the most optimal universal component for creating a growth substrate is variant K3 (mixture of „newly picked" and „old" SS) which has not so developed aboveground part but has very branched root system that allows to adapt to various environmental factors and in combination with a small proportion of natural sorbents can be effective for the recultivation of MSW landfills, which in its turn minimizes the need to use a fertile soil layer.

Key words: sewage sludge, waste processing, composting, substrates, bioindication, sorbents, recultivation.

1. Introduction

The problem of technogenically degraded lands especially when they are polluted due to inefficient human economic activity remains relevant in Ukraine and has a negative impact on the environment and human health. Effective recultivation of land resources from closed Municipal Solid Waste (MSW) landfills and unauthorized dumps has a high potential and requires the choice of an adequate strategy. First of all, society gets a number of environmental benefits and economic benefits from recultivation such as: use of renewable energy and resources that will turn into social benefits (transformation of degraded lands into aesthetic landscapes i.e., improving the city's infrastructure) (Kacprzak et al., 2017).

In accordance with the goals of sustainable development where the priority is environmental improvement and conservation of natural resources a 3R waste management strategy (Reduction, Reuse, Recycling) will be effective, that is we consider waste as available resources (Madadian et al., 2020; Savchuk et al., 2017; Kurylets et al., 2022). Therefore, technologies for processing secondary organic waste into useful secondary raw materials will help to improve the functioning of the circular economy (European Commission, 2018; Vanhamäki et al., 2020).

Among the available and effective methods of recultivation technology is the use of Sewage Sludge (SS). The use of sludge as a substitute for mineral fertilizers contributes to the formation and stabilization of the soil by decomposing organic substance which is severely disturbed in places contaminated with heavy metals. Environmental capabilities of SS also affect the physicochemical qualities of the soil (improving aggregation and infiltration capacity and increasing the availability of nutrients) (Antolín et al., 2005). Thus, the use of sludge in technologies of biological recultivation of degraded lands solves two problems – soil conditioning for reclaimed turf surface and their environmentally safe processing (Grekhova & Gilmanova, 2016).

Sludge can be considered as a substrate for fertilization and soil recultivation, as they are a source of significant concentrations of macro- and micronutrients in particular nitrogen, phosphorus, potassium which are considered as components of organo-mineral fertilizers of different composition and purpose to improve soil quality (Paya et al., 2018; Zhu et al., 2004; Tymchuk et al., 2021; Tymchuk et al., 2022). However, SS tends to accumulate heavy metals (Wu et al., 2015; Hei et al., 2016) and organic pollutants (Clarke & Smith, 2011), pharmaceuticals (Khan et al., 2021; Boillot et al., 2008). In addition, pathogenic microorganisms such as bacteria, viruses and viable helminth eggs are present in the sludge (Fijalkowski et al., 2014; Ye & Zhang, 2011). The application of composting technology leads to the recovery of sediments as a resource, enhances waste degradation and reduces the concentration of pharmaceuticals such as fluoroquinolones (Lillenberg et al., 2010; Li et al., 2015). Such reuse of SS is economically advantageous and environmentally sustainable compared to the method of waste disposal in landfills (Andersen, 2001; Wang et al., 2015; Onwosi et al., 2017).

The purpose of this scientific research is to carry out bioindication tests of growth substrates on the basis of composted SS with the subsequent possibility of their application in technologies of recultivation of solid waste landfills.

2. Materials and methods

2.1. Materials that are used in the experiment

As the main target raw materials for the development of model composting mixtures, mechanically dewatered „newly picked" SS (SS_n) were taken after centrifugation of the mixture of raw sediment and excess activated sludge in the mechanical dewatering shop of Lviv WWTP. In one of the mixtures the effect on the process of biocomposting of „old" SS (SS_{old}) was investigated. This sample of SS_{old} was selected at the operating sludge site of Lviv WWTP, its age is 2-3 years according to the registration book. When planning the composition of mixtures No. 1–No. 3 we take into account the regulatory-technological and ecological-sanitary requirements contained in the national standard of Ukraine DSTU 8727 (2017): „Sewage water sedimentation. Preparation of an organo-mineral mixture from sewage sludge account."

According to the results of laboratory studies of SSn, which were taken at the Lviv Wastewater Treatment Plant in accordance with DSTU 7369 (2013), contain sufficient amounts of phosphorus, potassium and nitrogen, macro- and microelements, as well as the available content of the organic component (23.8%) which can supply plants with nutrients. The content of heavy metals in the experimental samples of SS did not exceed the maximum permissible concentration. The neutral reaction of the acidity of the environment should not have an inhibitory effect on the growth and development of plants. The qualitative composition of fresh sewage sludge is given in the Table. 1.

According to sanitary and hygienic indicators the samples of all four composts did not contain bacteria of the genus *Salmonella* and viable eggs of helminths and the index of bacteria of the group of *Escherichia coli* did not exceed the norms regulated by DSTU 7369 (2013).

Table 1. Qualitative composition of fresh sewage sludge (Shkvirko et al., 2018)

Indicators	Units of measurement	Actual value	
		Dry substance	Natural humidity
Acidity: pH salt	pH	–	6.4
pH water	pH	–	6.1
Moisture	%	–	73.6
Ash	%	23.8	–
Total Phosphorus	%	1.6	0.42
Total potassium	%	0.3	0.08
Total nitrogen	%	3.56	0.93
Ammonium nitrogen	%	0.28	0.073
Nitrogen nitrate (in peat)	mg/100r	11.75	–
Calcium (as soil)	mmol/100r	11.75	–
Magnesium (as soil)	mmol/100r	4.12	–
Sulfur mobile (in the soil)	mg/kg	14.8	–
Minerals: copper (Cu)	mg/kg	–	4.0
zinc (Zn)	mg/kg	–	17.6
manganese (Mn)	mg/kg	–	45.1
cobalt (Co)	mg/kg	–	2.86
iron (Fe)	mg/kg	–	65.0
lead (Pb)	mg/kg	–	1.56
cadmium (Cd)	mg/kg	–	0.2
boron (B)	mg/kg	–	4.01

* **The** research was conducted in Lviv branch office of the State institution "Soils protection institute of Ukraine".

Table 2 shows the composition of composting mixtures with volumes of each of the components of mixtures #1 – #4 and the corresponding volume fractions of the components.

Wood chips were used as a plant filler in all studied mixtures. In all studied compositions recirculating-active biocompost aged about 2 weeks was used taken from the middle part of the compost piles of the biocomposting station of LCP "Green City" in order to accelerate the development of the biocomposting process.

The calculated masses of organic carbon and nitrogen in the four studied mixtures and the calculated C/N ratios at the beginning of the biocomposting process are given in the Table 2. Estimated concentrations of organic carbon and nitrogen in SS and wood chips are accepted as average values according to the results of previous studies of similar raw materials (Białobrzewski at al., 2015; Rynk, 1992):

– carbon and nitrogen content in SS: 250 g/kg of dry substance and 31 g/kg of dry substance respectively (C/N ≈ 8.1);
– carbon and nitrogen content in wood chips: 475 g/kg of dry substance and 2.4 g/kg CF respectively (C/N ≈ 200).

The mass concentrations of carbon and nitrogen in the active compost selected from the piles of the biocomposting plant are estimated at 300 g/kg of dry substance and 20 g/kg of dry substance, respectively (C/N = 15).

Therefore, based on the results of the research on the samples of the SS we can conclude that their chemical composition is relatively safe and it is possible to use them as a growth substrate.

Table 2. Volume ratios of the components of the mixtures at the beginning of composting under laboratory conditions

Number of mixtures	Volume, dm^3					Volume fraction			
	SS_n	SS_{old}	wood chips	active compost	total	SS_n	SS_{old}	wood chips	active compost
1	3	0	6	3	12	0.250	0	0.500	0.250
2	4	0	4	4	12	0.333	0	0.333	0.333
3	2	2	4	4	12	0.167	0.167	0.333	0.333
4	0	0	0	12	12	0	0	0	1.000

Table 3. Estimated ratios of the mass content of carbon and nitrogen (C/N) in the raw material mixtures before composting

Mixture number	Mass of carbon, g				Mass of nitrogen, g				C/N of mixture
	SS	wood chips	active compost	total	SS	wood chips	active compost	total	
1	151.8	358.0	205.4	715.1	18.8	1.8	13.7	34.3	20.8
2	202.4	238.6	273.9	714.9	25.1	1.2	18.3	44.6	16.0
3	202.4	238.6	273.9	714.9	25.1	1.2	18.3	44.6	16.0
4	0.0	0.0	821.6	821.6	0.0	0.0	54.8	54.8	15.0

2.2. Research methodology

This investigation was conducted in accordance with the current national standards of Ukraine: DSTU ISO 11269-1 (2004): "Soil quality. Determination of the effect of pollutants on soil flora. Part 1: Method for determining the inhibitory effect on root growth"; DSTU ISO 11269-2 (2002): "Soil quality". Determination of the effect of pollutants on soil flora. Part 2: The effect of chemicals on the germination and growth of higher plants". In the course of the experiment germination, mass and length of the aerial and root systems were recorded. Rye grass (*Lolium perenne* L.) which belongs to category 1 – monocot plants was used as a bioindicator plant.

The scheme of bioindication tests consisted of four types of compost to each of which was added a natural sorbent – zeolite in percentage: 0; 2.5; 5; 7.5, dark grey podzolic soil was used as a control element. Soil samples before the experiment were screened through a sieve with square holes of 4 to 5 mm, to remove coarse fragments. Substrates were brought to the same humidity.

10 seeds of ryegrass (*Lolium perenne* L.) were planted in a 200 ml container with the created substrate. To ensure the reliability of the research and minimize mistakes the experiments were performed three times. Irrigation was carried out with settled tap water every two days by drip irrigation. During the implementation of the experiment the following indicators were observed: time and number of sprouts per day; general germination. At the end of the experiment the length and weight of the aboveground part of the plant and the length as well as the weight of the roots were also measured. Measuring the length and weight of the aboveground part of the plant and measuring the length and weight of the roots were of paramount importance. The room where the experiments were conducted maintained a constant temperature (23–25°C), humidity (55-60%) and lighting (4 phytolamps with light output of 1400 Lm). For better scattering of the artificial light source all side surfaces of the laboratory were covered with reflective and heat-insulating film (Fig.1).

3. Results and discussion

In this scientific research biotesting of four substrates based on compost #1-4 for seed germination helps us to establish the effectiveness of the composting process to eliminate phytotoxicity of substances.

The first sprouts of ryegrass began to appear on the 7th day of the experiment. The results of changes in ryegrass

Figure 1. General view of the thermostated room with test samples

Table 4. Data on ryegrass germination in the studied substrates

Substrate variant	Zeolite content	Germination of ryegrass, %								
		7	14	21	28	35	42	49	56	60
Soil	0%	80.0	80.0	80.0	80.0	80.0	76.7	76.7	76.7	76.7
	2.5%	86.7	90.0	90.0	90.0	90.0	86.7	86.7	86.7	86.7
	5%	**90.0**	93.3	93.3	90.0	90.0	90.0	90.0	90.0	90.0
	7.5%	86.7	90.0	90.0	83.3	83.3	83.3	83.3	83.3	83.3
K1	0%	76.7	93.3	93.3	83.3	83.3	83.3	83.3	83.3	83.3
	2.5%	66.7	90.0	83.3	83.3	83.3	83.3	83.3	83.3	83.3
	5%	73.3	86.7	90.0	**100.0**	96.7	93.3	90.0	90.0	90.0
	7.5%	73.3	83.3	80.0	83.3	86.7	83.3	83.3	83.3	83.3
K2	0%	66.7	83.3	73.0	73.0	73.0	73.0	73.0	73.0	73.0
	2.5%	80.0	83.3	83.3	86.7	90.0	90.0	90.0	90.0	86.7
	5%	63.3	80.0	80.0	83.3	80.0	76.7	76.7	76.7	76.7
	7.5%	**90.0**	90.0	90.0	90.0	86.7	86.7	86.7	86.7	83.3
K3	0%	33.3	86.7	93.3	93.3	90.0	86.7	86.7	86.7	86.7
	2.5%	16.7	56.7	83.3	90.0	90.0	90.0	86.7	86.7	86.7
	5%	3.3	70.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
	7.5%	20.0	70.0	86.7	90.0	90.0	86.7	86.7	86.7	86.7
K4	0%	20.0	63.3	76.7	80.0	80.0	80.0	80.0	80.0	80.0
	2.5%	6.7	70.0	83.3	86.7	90.0	93.3	96.7	93.3	93.3
	5%	0.0	63.3	83.3	83.3	83.3	83.3	80.0	80.0	76.7
	7.5%	0.0	63.3	76.7	86.7	86.7	90.0	90.0	90.0	90.0

culture for every 7 days during the experiment are shown in Table 4.

As we can see from the above results the first sprouts of ryegrass began to appear on the 7th day of the experiment. The highest average value on the seventh day of germination was 90% in the sample with sorbent content of 5% (Substrate variant – Soil) and also in substrate variant K2 based on compost #2, which consisted of equal volumes of $SS_{n\ (newly\ picked)}$, wood chips and active compost in the sample with sorbent content of 7.5%. It should be noted that the first plant sprouts in substrate variants K3 and K4 appeared later compared with substrate variants K1, K2, and control (Soil). For the substrate variant K1 in the sample with a sorbent content of 5% plant germination was the largest and was 100%.

Figure 3 shows a graph comparing the average germination of ryegrass grouped by sorbent (zeolite) content in the studied variants of substrates on the last 60th day of the experiment.

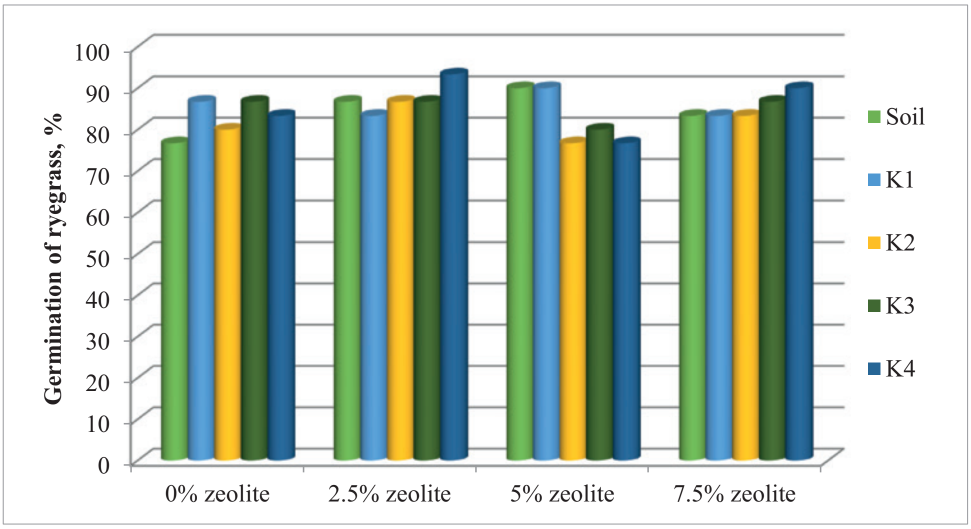

Figure 2. Average germination of ryegrass in the studied samples on the 60th day

As we can see from Figure 2 on the last day of the experiment in samples of variants with zeolite content of 0% the highest average value of plant germination was observed in variants of substrates K1-K4 compared with the control sample (Soil) with a difference of 4.3-13%. If we compare the samples (K1, K2, K3, K4) with a zeolite content of 2.5% with a control sample with a zeolite content of 0%, the average germination rate at the end of the experiment was 83.3%, 86.7%, 86.7 %, 93.3% respectively against 76.7%. Among the samples with a zeolite content of 5%, the highest germination rate was in the substrate K1 and was 90%. Samples K3 and K4 with a zeolite content of 7.5% had the best germination rates compared to variants K1 and K2, and were 86.7%, 90% respectively against 83.3% in both variants.

Figure 3 shows the general view of ryegrass in the studied substrates on the 60th day of the experiment.

At the final stage of the research on the 60th day (Fig. 3) in the control variant ryegrass stalks were wider in samples containing sorbent. Ryegrass stalks in variant K1 were narrower and drier. In variant K3 the presence of fungal flora was noted (Fig. 4) which could have an inhibitory effect on growth and development of plants. Variant K4 differed from others by wider and branched stalks.

After completion of the experiment measurements of plant mass, as well as the length and mass of the aboveground part and the root of plants were performed to keep records of the influence of substrate composition on plant growth and development. The measurement results are shown in the Table 5.

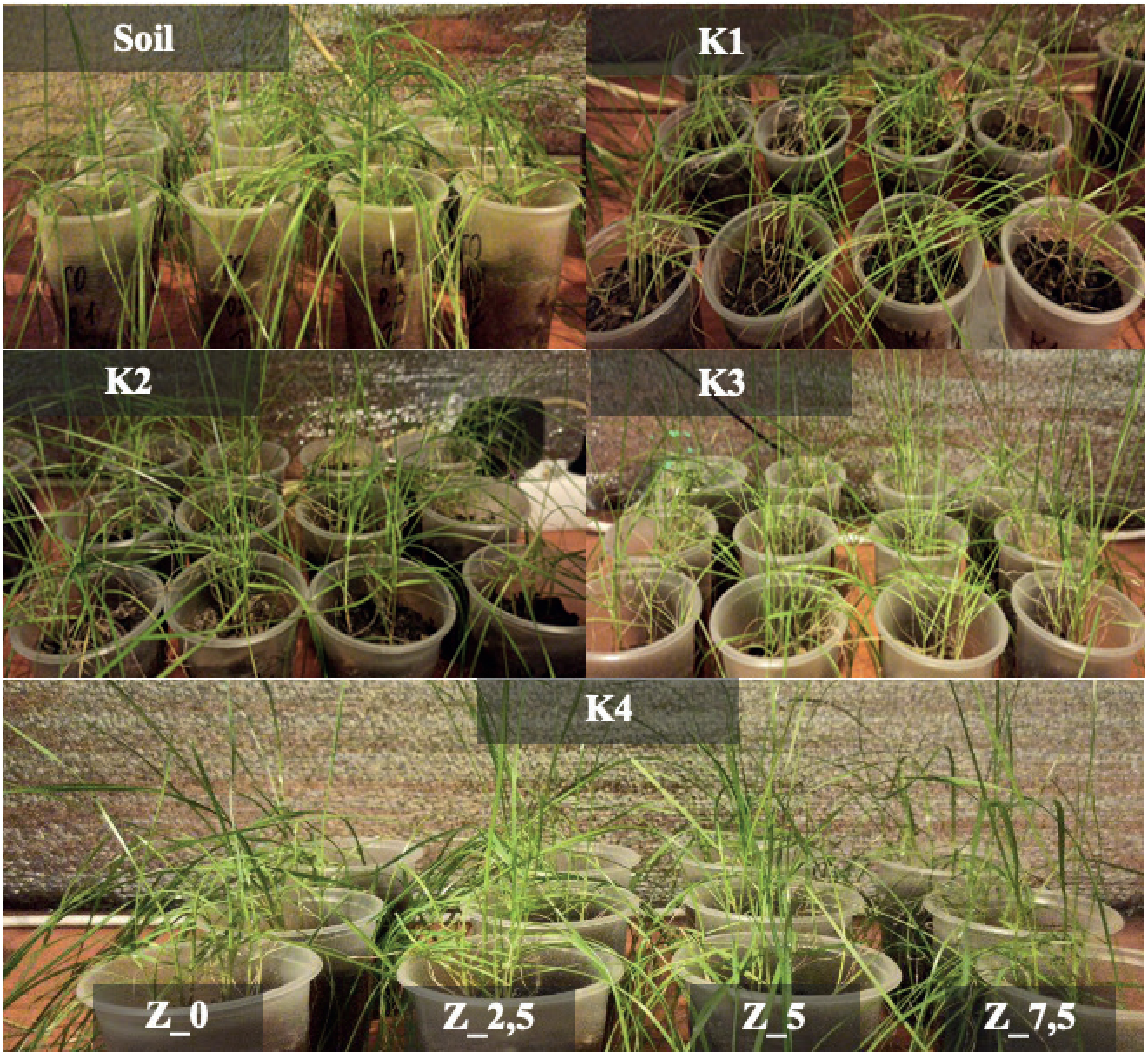

Figure 3. General form of plants on the 60th day

Table 5. Changes in the growth and development of ryegrass depending on the use of different types of substrates

Variant	Average height of the ground part of the plant, cm	Average root length, cm	Average weight, g	Average weight of the ground part of the plant, g	Average weight of roots, g
0% zeolite					
Soil	23.51	1.86	0.114	0.090	0.024
K1	**13.23**	1.82	0.067	0.046	0.021
K2	17.22	2.7	0.096	0.054	0.042
K3	19.06	5.06	0.181	0.114	0.067
K4	**24.63**	7.42	0.173	0.127	0.046
2.5 % zeolite					
Soil	23.45	1.85	0.127	0.100	0.028
K1	15.29	1.54	0.103	0.047	0.056
K2	18.22	2.25	0.088	0.056	0.031
K3	17.57	4.57	0.164	0.090	0.074
K4	19.82	6.13	0.161	0.094	0.067
5 % zeolite					
Soil	20.96	1.07	0.110	0.090	0.020
K1	14.28	1.81	0.080	0.039	0.041
K2	18.16	2.48	0.085	0.062	0.023
K3	17.12	5.77	0.176	0.104	0.072
K4	18.9	4.55	0.169	0.100	0.069
7.5 % zeolite					
Soil	23.45	2.05	0.178	0.136	0.042
K1	19.04	2.72	0.078	0.052	0.026
K2	17.37	2.77	0.091	0.051	0.041
K3	18.1	5.56	0.156	0.093	0.063
K4	18.81	3.44	0.088	0.067	0.021

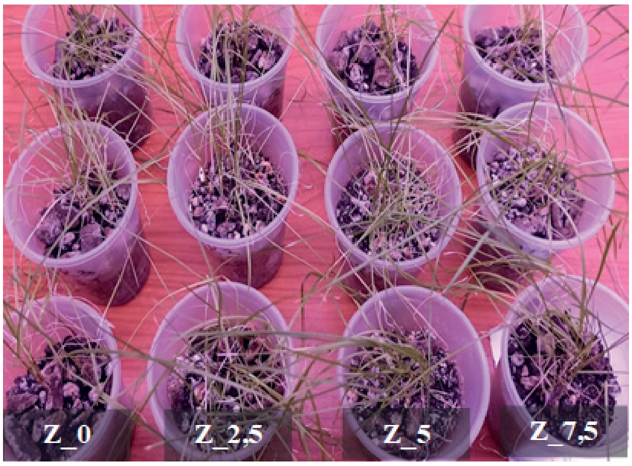

Figure 4. General appearance of plants on the 50th day of variant K3

According to the obtained results which are presented in Figure 5 the highest average value of the length of the ryegrass stem is observed in variant K4 in the sample with zeolite content of 0% and was 24.63 cm. In variant K1 in the sample without zeolite the lowest average value of stem length was 13.23 cm. It should be noted that the average values of ryegrass stem length of variants K1, K2, K3 were smaller than the control variant. It should also be noted that the average height of ryegrass stems in variants K1, K2, K3 with sorbent content is higher than in these samples with sorbent content of 0% by 43% (sorbent content 7.5%), 6% (sorbent content 2.5%) and 9.7% (sorbent content 7.5%), respectively.

As for the length of the roots there are more noticeable changes. As we can see from fig. 6 in variant K3 and K4 there is a more developed root system in comparison with other variants. Thus, the highest average value of root length is observed in variant K4 in the sample with a zeolite content of 0% and is 7.42 cm. The lowest value in the control variant with a zeolite content of 5%. For variant K3, the largest average value of root length in the sample with a sorbent content of 5%, and is 5.77 cm, which is 5.4 times more than the control variant with a sorbent content of 5%.

Figure 7 shows that the highest average weight of one ryegrass plant is in the control variant with a zeolite content of 7.5% and in the variant K3 with a zeolite content of 5%. It should also be noted that the average weight of one plant

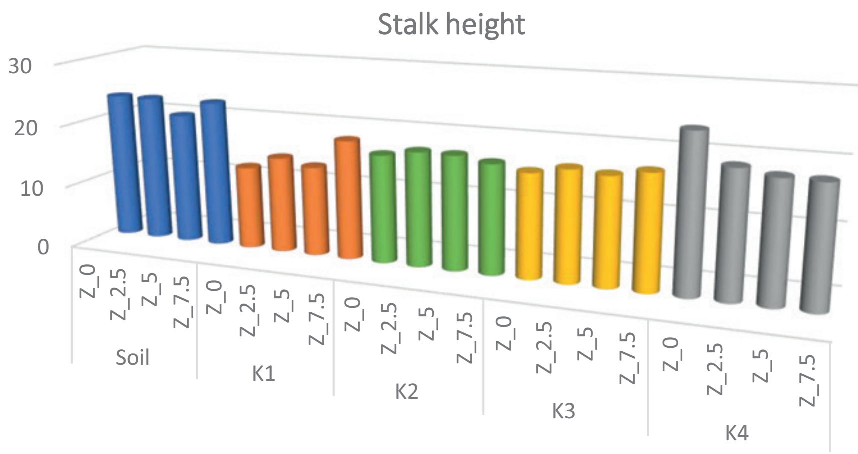

Figure 5. Changes in stalk height depending on the use of different types of substrates

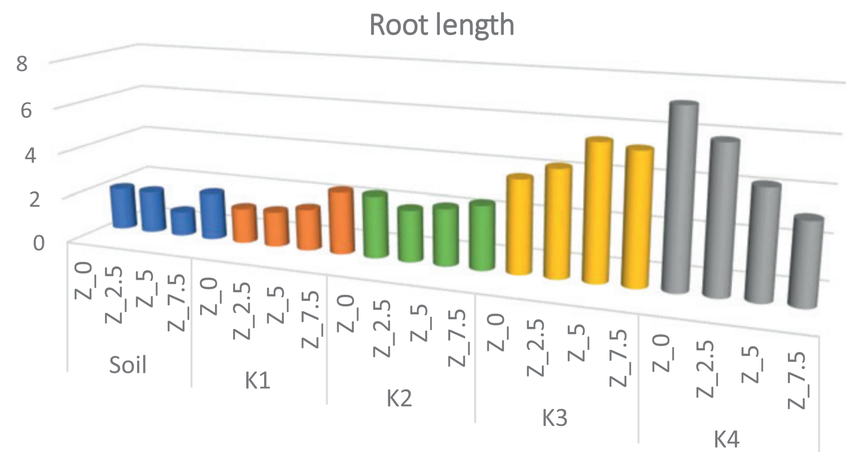

Figure 6. Changes in root length depending on the use of different types of substrates

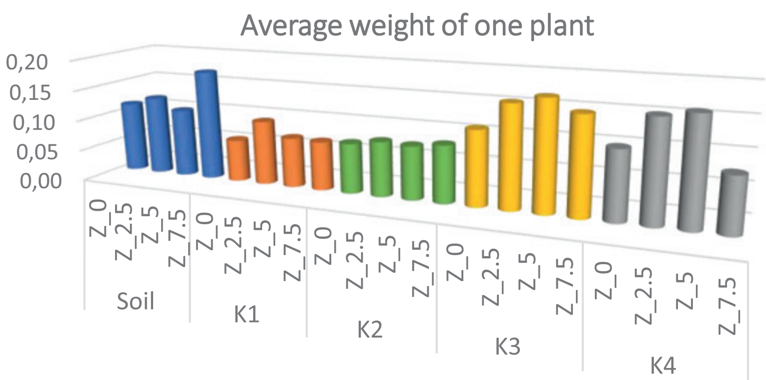

Figure 7. Change in the average weight of one plant depending on the type of substrate

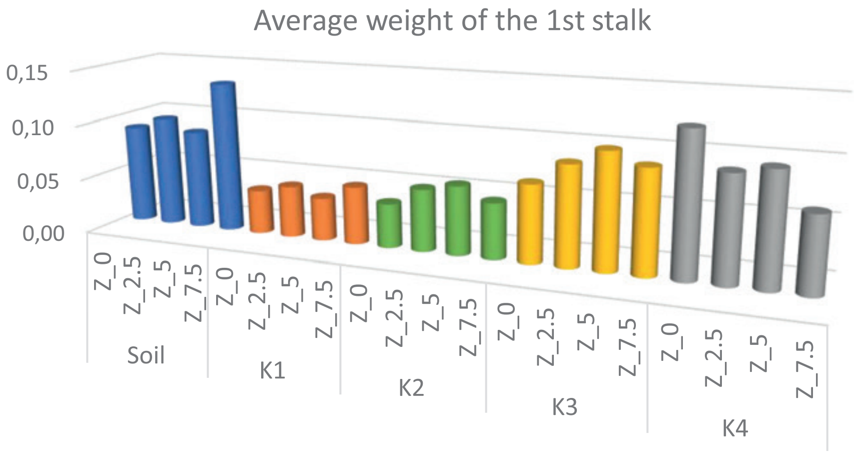

Figure 8. Change in the average weight of the 1st stalk depending on the type of substrate

in variant K3 in the samples with sorbent content of 2.5% and 5% is higher compared to the control variant by 23% and 63% respectively.

The largest value of the average weight of the stalk as seen in fig. 8 was in the control variant (soil) in the sample with a sorbent content of 7.5% and was 0.14 g. In variants K3 and K4 the average values of such indicators as root length, weight of one plant and weight of one stalk were greater than in variants K2 and K3.

The results we obtained show that the substrates from composted sewage sludge allow the growth of plants. Studies (Manca et al., 2020) on the use of sediments as part of the growth substrate allow to increase the height of plants (eucalyptus) by 19%, the total weight of plants by 17%, but the total mass of roots decreases by ~5%. The authors also point out that such reuse of sediments makes it possible to limit the unproductive disposal of these materials in landfills, thus avoiding the associated environmental problems and unnecessary costs.

Another approach (Abaurre et al., 2021) notes that the addition of sewage sludge increases nutrient content, retains moisture, and thus allows for better plant development.

Organic compounds such as sewage sludge have a high density and consequently low overall porosity (Raviv, 2013) but we observed that the addition of structuring materials (wood chips) in the composting process made these materials suitable for creating a growth substrate. Research (Gabira et al., 2021) was conducted to create a sediment-based substrate for growing forest seedlings. They note the successful use of sediment as a component of the substrate. As structuring materials in their study, they used eucalyptus bark and sugar cane pulp, as the authors note, this made it possible to increase the micro- and macroporosity of the substrate. The authors (Meng et al., 2020) also note the feasibility of using additional components in composting, in this study it is molasses and spent mushroom substrate.

The increase in the amount of sewage sludge and stricter legislative regulation of issues related to their placement and burial cause the need for the development of new technologies to ensure their effective processing which will be economically justified and ecologically clean methods of disposal. As reported (Luis et al., 2019) the utilization of organic substances by the method of composting allows processing nutrients and organic substances into mineral fertilizers and helps to close the cycle of waste management which is an important part of the circular economy.

Researchers (Xu et al., 2012) reported that SS is a useful and suitable raw material for the production of P-fertilizers. SS-based composts improve crops and biomass productivity (Zhang et al., 2014) and soil characteristics such as porosity, bulk density, water holding capacity and aggregate stability.

Tymchuk et al. (2021) confirms the positive effect of adding natural sorbents to the composition of the substrate and notes that there are noticeable positive changes in the growth and development of plants.

About the positive effect of adding natural sorbents to the composition of the substrate, Tymchuk notes that there are noticeable positive changes in the growth and development of plants.

The plant germination test was commonly used to assess phytotoxicity and compost maturity (El Fels et al., 2014). According to (Tiquia et al., 1996) plant germination greater than 80% percent indicates phytotoxicity-free and mature compost. The results showed that the percentage of plant germination was highest in K1 (100%), but the stems of the plants were thin, narrow and with withered ends.

Based on the obtained data it can be assumed that the most optimal universal component for creating a growth substrate is variant K3 (mixture of "newly picked" and "old" SS) which has not so developed aboveground part but has very branched root system that allows to adapt to various environmental factors and in combination with a small proportion of natural sorbents can be effective for the recultivation of MSW landfills, which in its turn minimizes the need to use a fertile soil layer.

4. Conclusion

Finally, we can draw the following conclusions:

1. researching has been conducted on the use of compost whose raw material contains a mixture of "newly picked" and "old" SS. The studies have confirmed the prospects for the use of "old" SS, which makes it possible to recommend such a compost composition for real implementation, allowing the disposal of SS which is accumulated and stored in large quantities.
2. according to the bioindication data, the optimum for usage such as a growth substrate is the K3 variant with the ratio of SS_n: SS_{old}: wood chips: active compost = 2:2:4:4. In the case of using raw materials of this composition for the creation of compost, the plants used for biotesting did not have an overly developed ground part but have a very branched root system which allows them to adapt to various environmental factors.
3. the use of compost based on a mixture of SS_n and SS_{old} allows not only to solve the problem of reclamation with a minimum of fertile soil layer, but also to ensure a reduction in environmental risk due to the negative impact on the environment of SS_{old} accumulated and stored in sewage treatment plants, which are formed daily in significant quantities of SS_n.

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References

Abaurre G.W., Alonso J.M., Júnior O.J.S. & de Faria S.M., 2021, Sewage sludge compared with other substrates in the inoculation, growth, and tolerance to water stress of samanea saman. Water (Switzerland) 13(9). doi:10.3390/w13091306

Andersen A., 2001, Disposal and Recycling Routes for Sewage Sludge – Part 3. Scientific and Technical Sub-Component Report, 23 October 2001.

Antolín M.C., Pascual I., García C., Polo A. & Sánchez-Díaz M., 2005, Growth, yield and solute content of barley in soils treated with sewage sludge under semiarid Mediterranean conditions. Field Crop Res. 94: 224–237.

Białobrzewski I., Mikš M., Krajnik Dach J., Markowski M. & Czekała W., 2015, Model of the sewage sludge-straw composting process integrating different heat generation capacities of mesophilic and thermophilic microorganisms. Waste Manag. 43: 72–83.

Boillot C., Bazin C., Tissot-Guerraz F., Droguet J., Perraud M., Cetre J.C., et al., 2008, Daily physicochemical, microbiological and ecotoxicological fluctuations of a hospital effluent according to technical and care activities. Science of The Total Environment 403(1–3): 113–129. doi:10.1016/j.scitotenv.2008.04.037

Clarke B.O. & Smith S.R., 2011, Review of "emerging" organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. Environ. Int. 37: 226–247. https://doi.org/10.1016/j.envint.2010.06.004

DSTU 7369, 2013, Wastewater. Requirements for wastewater and its sediments for irrigation and fertilization of 22 August 2013.

DSTU 8727, 2017, Sewage sludge. Preparation of organo-mineral mixture from sewage sludge of 31 July 2017.

DSTU ISO 11269-1, 2004, Soil quality. Determination of the effects of pollutants on soil flora. Part 1: Method for the measurement of inhibition of root growth of 30 April 2004.

DSTU ISO 11269-2, 2002, Soil quality. Determination of the effects of pollutants on soil flora. Part 2: Effects of chemicals on the emergence and growth of higher plants of 12 July 2002.

El Fels L., Zamama M., El Asli A. & Hafidi M., 2014, Assessment of biotransformation of organic matter during co-composting of sewage sludge-lignocelullosic waste by chemical, FTIR analyses, and phytotoxicity tests. International Biodeterioration & Biodegradation 87: 128–137.

European Commission, 2018, Research and Innovation. A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment, Updated Bioeconomy Strategy. https://doi.org/10.2777/792130

Fijalkowski K.L., Kacprzak M.J. & Rorat A., 2014, Occurrence changes of Escherichia coli (including O157:H7 serotype) in wastewater and sewage sludge by quantitation method of (EMA) real time—PCR. Desalination and Water Treatment 52(19-21): 3965–3972. doi:10.1080/19443994.2014.887499

Gabira M.M., da Silva R.B.G., Bortolheiro F.P.A.P., Mateus C.M.D., Villas Boas R.L., Rossi S., et al., 2021, Composted sewage sludge as an alternative substrate for forest seedlings production. IForest 14(6): 569–575. doi:10.3832/ifor3929-014

Grekhova I. & Gilmanova M., 2016, The usage of sludge of wastewaterin the composition of the soil for land reclamation. Procedia Engineering 165: 794–799.

Hei L., Jin P., Zhu X., Ye W. & Yang Y., 2016, Characteristics of speciation of heavy metals in municipal sewage sludge of guangzhou as fertilizer. Procedia Environ. Sci. 31: 232–240. https://doi.org/10.1016/j.proenv.2016.02.031

Kacprzak M., Neczaj E., Fijałkowski K., Grobelak A., Grosser A., Worwag M., Rorat A., Brattebo H., Almas A. & Singh B.R., 2017, Sewage sludge disposal strategies for sustainable development. Environmental Research: 156: 39–46. doi:10.1016/j.envres.2017.03.010

Khan N.A., Vambol V., Vambol S., Bolibrukh B., Sillanpaa M., Changani F., et al., 2021, Hospital effluent guidelines and legislation scenario around the globe: A critical review. Journal of Environmental Chemical Engineering 9(5): 105874. doi:10.1016/j.jece.2021.105874

Kurylets O., Helesh A., Vasiichuk V., Znak Z. & Romaniv A., 2022, Coagulation treatment of effluent from milk-processing enterprises with waste FeSO4. Eastern-European Journal of Enterprise Technologies 1(10(115): 17–23. https://doi.org/10.15587/1729-4061.2022.252309

Li Y., Liu B., Zhang X., Gao M. & Wang J., 2015, Effects of Cu exposure on enzyme activities and selection for microbial tolerances during swine-manure composting. Journal of Hazardous Materials 283: 512–518. doi:10.1016/j.jhazmat.2014.09.061

Lillenberg M., Yurchenko S., Kipper K., Herodes K., Pihl V., Lõhmus R., Ivask M., Kuu A., Kutti S., Litvin S.V. & Nei L., 2010, Presence of fluoroquinolones and sulfonamides in urban sewage sludge and their degradation as a result of composting. Int. J. Environ. Sci. Technol. 7: 307–312. https://doi.org/10.1007/ BF03326140

Luis A.B.P., Barbara S.B., Rafael M.D., Daniel J. & Rosane A.G.B., 2019, Organic solid waste management in a circular economy perspective – A systematic review and SWOT analysis. Journal Cleaner Production 239: 118086. https: doi.org/10.1016/j.jclepro.2019.118086

Madadian E., Haelssig J.B. & Pegg M., 2020, A Comparison of Thermal Processing Strategies for Landfill Reclamation: Methods, Products, and a Promising Path Forward. Resources, Conservation and Recycling 160: 104876. doi:10.1016/j.resconrec.2020.104876

Manca A., da Silva M.R., Guerrini I.A., Fernandes D.M., Villas Bôas R.L., da Silva L.C., et al., 2020, Composted sewage sludge with sugarcane bagasse as a commercial substrate for eucalyptus urograndis seedling production. Journal of Cleaner Production 269: 122145. doi:10.1016/j.jclepro.2020.122145

Meng L., Li W., Zhang X., Zhao Y., Chen L. & Zhang S., 2020, Influence of spent mushroom substrate and molasses amendment on nitrogen loss and humification in sewage sludge composting. Heliyon 6(9): e04988. doi:10.1016/j.heliyon.2020.e04988

Onwosi C.O., Igbokwe V.C., Odimba J.N., Eke I.E., Nwankwoala M.O., Iroh I.N. & Ezeogu L.I., 2017, Composting technology in waste stabilization: On the methods, challenges and future prospects. Journal of Environmental Management 190: 140–157.

Paya J., Monzo J., Borrrachero M.V. & Soriano L., 2018, Sewage sludge ash, [in:] J. Brito, F. Agrela (eds), New trends in Eco-Efficient and Recycled Concrete, 1st Edition, p. 121–152. Woodhead Publishing Series in Civil Structural Engineering.

Raviv M., 2013, Composts in growing media: what's new and what's next? Acta Horticulturae 982: 39–52. doi: 10.17660/ActaHortic.20 13.982.3

Rynk R. (ed.), 1992, On-Farm Composting Handbook. Northeast Regional Agricultural Engineering Service (NRAES-54), 152 Riley-Robb, Cooperative Extension, Ithaca, NY, 187 pp.

Savchuk L., Znak Z., Kurylets O., Mnykh R. & Olenych R., 2017, Research into processes of wastewater treatment at plants of meat processing industry by flotation and coagulation. Eastern-European Journal of Enterprise Technologies 3(10(87)): 4–9. https://doi.org/10.15587/1729-4061.2017.101736

Shkvirko O., Tymchuk I. & Malovanyy M., 2018, The use of bioindication to determine the possibility of sludge recovery after biological treatment of wastewater. Environmental Problems 3(4): 258–264.

Tiquia S.M., Tam N.F.Y. & Hodgkiss I.J., 1996, Effects of composting on phytotoxicity of spent pig-manure sawdust litter. Environmental Pollution 93(3): 249–256.

Tymchuk I., Malovanyy M., Bota O., Shkvirko O. & Popovych O., 2022, Biological reclamation using a sewage sludge-based substrate – A way to ensure sustainable development of urban areas. Ecological Engineering and Environmental Technology 23(1): 34–41. doi:10.12912/27197050/143029

Tymchuk I., Malovanyy M., Shkvirko O. & Yatsukh K., 2021, Sewage sludge as a component to create a substrate for biological reclamation. Ecological Engineering and Environmental Technology 22(4): 101–110. doi:10.12912/27197050/137863

Vanhamäki S., Virtanen M., Luste S. & Manskinen K., 2020, Transition towards a circular economy at a regional level: A case study on closing biological loops. Resources, Conservation and Recycling 156: 104716. doi:10.1016/j.resconrec.2020.104716

Wang X.Q., Cui H.Y., Shi J.H., Zhao X.Y., Zhao Y. & Wei Z.M., 2015, Relationship between bacterial diversity and environmental parameters during composting of different raw materials. Bioresour. Technol. 198: 395–402.

Wu Q., Cui Y., Li Q. & Sun J., 2015, Effective removal of heavy metals from industrial sludge with the aid of a biodegradable chelating ligand GLDA. Journal of Hazardous Materials 283: 748–754. doi:10.1016/j.jhazmat.2014.10.027

Xu H., He P., Gu W., Wang G. & Shao L., 2012, Recovery of phosphorus as struvite from sewage sludge ash. J. Environ. Sci. 24: 1533–1538. https://doi.org/10.1016/S1001- 0742(11)60969-8

Ye L. & Zhang T., 2011, Pathogenic bacteria in sewage treatment plants as revealed by 454 pyrosequencing. Environ. Sci. Technol. 45: 7173–7179. https://doi.org/10.1021/es201045e

Zhang L., Sun X., Tian Y. & Gong X., 2014, Biochar and humic acid amendments improve the quality of composted green waste as a growth medium for the ornamental plant Calathea insignis. Sci. Hortic. (Amst.) 176: 70–78. https://doi.org/ 10.1016/j.scienta.2014.06.021

Zhu N., Deng Ch., Xiong Y. & Qian H., 2004, Performance characteristics of three aeration systems in the swine manure composting. Bioresour. Technol. 95: 319–326. doi:10.1016/j.biortech.2004.02.021