ENVIRONMENTAL PROBLEMS

Vol. 7, No. 3, 2022

OBTAINING AND USING SUBSTRATES WITH SEWAGE SLUDGE

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https://doi.org/10.23939/ep2022.03.154

Received: 20.07.2022

Abstract. The article is devoted to the study of the prospects of using compost with sewage sludge in the raw material for the recultivation of disturbed lands. A special installation was used for bio-composting, which allowed controlling of the process parameters. The results of bio-indication of composts obtained under different conditions of compositions of the raw material mixture are given. Based on the analysis of the results of bio-indication, the optimal composition of the raw material mixture using "fresh" and "old" sewage sludge is established. An analysis of the parameters of the bio-indication process was carried out for this compost of optimal composition, which makes it possible to develop recommendations for the implementation of the process in industrial conditions.

Keywords: compost, sewage sludge, bio-indication, raw materials, process, recultivation, zeolite, bio-composting.

1. Introduction

The problem of technogenic degraded lands in Ukraine and the world poses a significant threat to environmental security. We can distinguish three main types of facilities that need to be restored most: mining quarries, the rapid development of which took place in the second half of the twentieth century; solid waste landfills and dumps, which are the main element of waste management system in developing countries; and slag heaps.

With the destruction of the soil cover, man-made landscapes are formed, which slow down the self-restoration of vegetation and soils. It is possible to reduce or eliminate this negative man-made impact on the environment of such landscapes with the help of recultivation technology: the creation of forest plantations, covering disturbed lands with fertile soil layer, strengthening of surface grass cover, chemical reclamation, removal of the top layer of soil with its subsequent use to restore vegetation, the introduction of natural zeolites (Hrechanyk et al., 2022).

Using substrates synthesized with organ-containing waste and natural sorbents in exchange for using fertile lands is quite promising. To increase the level of environmental safety and in accordance with the principles of sustainable development, industrialized countries have begun to adopt laws and programs aimed at protecting and restoring the environment damaged by mining. Countries such as the United States, Germany, Poland, and the United Kingdom have begun to pay close attention to recultivating technologies. (Antwi et al., 2014; Fijalkowski et al., 2018).

On the other hand, one of the most important current environmental problems is the disposal and removal of sludge from the sludge sites of sewage treatment plants. Among the various wastewater treatment options, composting has gained widespread popularity due to its associated benefits such as waste sanitation and the conversion of waste into value-added products (Qian et al., 2014), weight and volume reduction (i.e. improved controllability) and environment pollution reduction. (Bernal et al., 2017; Wang at all., 2018). Thus, mineral nutrients are processed – nitrogen (N), phosphorus (P) and potassium (K) (Zhou et al., 2018; Wang et al., 2015). Composting technology is receiving increasing attention as an environmentally friendly way of disposal of organic waste (Zhang et al.,

For citation: Malovanyy, M., Storoshchuk, U. (2022). Obtaining and using substrates with sewage sludge. *Journal Environmental Problems*, *7*(3), 154–162. DOI: https://doi.org/10.23939/ep2022.03.154

2014). Researchers (Raut et al., 2008) have suggested that composting helps to manage large amounts of organic waste under sustainable management. A properly managed composting process provides a stable result and a harmless end product that can be used as a soil conditioner, a fertilizer which does not pose any threat to the environment, and a valuable component for reclamation substrates (Vaverková et al., 2020). It has recently been shown that compost from organic waste is of better quality than commercial inorganic fertilizers (Chowdhury et al., 2015). According to (Hermann et al., 2011; Banegas et al., 2007), composts can replace soil conditioners to support the formation of humus, which cannot be achieved artificially. Compost improves the water holding capacity of the soil (Mohammad et al., 2012).

There is a significant problem in the management of degraded soils: they are relatively poor in nutrients necessary for the normal functioning of plants. Therefore, an important step is ensuring proper fertilization of soils to obtain all necessary nutrients. Among the available and effective methods of meliorative technology is using sewage sludge (SS). The use of SS as a substitute for fertilizers contributes to the formation and stabilization of the soil by decomposing organic matter, which is largely disturbed in places contaminated with heavy metals. The environmental potential of SS also affects the physicochemical properties of the soil (improving aggregation and infiltration capacity and increasing the availability of nutrients) (Grekhova et al., 2016). Thus, the use of SS in technologies for biological recultivation of degraded lands solves two problems – soil conditioning for recultivated turf surface and environmentally safe processing of SS. Researchers (Seaker et al., 1983) note the positive results of recultivation of disturbed areas (landfills) when using SS with sand and peat in a ratio of 1:2:2 and soaking the seeds in a humic growth regulator for plant development. When adding this mixture to the landfill, the rate of seed germination increases significantly. Researchers (DSTU 8727:2017) report the successful use of sludge as a correction for acidic materials falling out of mines. Thus, in Pennsylvania, a single application of sludge with calculations up to 184 Mg/ha created a lush cover of forage plant species on the reconstructed bitumen strip of the mine with equal pH.

The accumulation of large amounts of SS is a particularly pressing environmental problem in Ukraine. This interferes with the normal operation of the sewage treatment plants (STP) and leads to pollution of all components of the environment. The vast majority of Ukrainian STP does not perform deep processing and disposal of SS, and the main method of dehydration and stabilization is the storage of SS on sludge sites. The increase in the amount of sludge and stricter legal regulation of their placement and burial require the development of new technologies to ensure their efficient processing. Thus, the complex utilization of SS solves not only environmental problems (reduces the need for fertile soil, and allows for disposal of a significant part of organ-containing waste) but also economic by obtaining secondary raw materials.

The composting process is influenced by factors that are classified into two groups:

– depending on the composition of the compost mixture such as nutrient balance, pH, particle size, porosity, humidity;

– depending on the process control such as O_2 concentration, temperature, water content and compaction (Liu et al., 2011).

Control of parameters such as temperature, pH, C/N ratio, bulk density, porosity, nutrient content, particle size, humidity and oxygen supply are crucial to get an accurate idea of the optimal process conditions. During the composting process, microorganisms need C, N, P and K as the main nutrients (organic C which decomposes) for energy supplement and developmental activity (Iqbal et al., 2015). In addition to these factors, a group of researchers (Bernal et al., 2009) suggests that the ability to decompose waste during composting may also vary depending on the chemical components of waste, the natural load and microbial efficiency in the compost matrix. Similarly, environmental conditions can directly affect the microbial activity and the rate of degradation of organic matter during composting (Hueso et al., 2012). Weather conditions (temperature and humidity) in the study area may also be important.

In the research, we aimed to use the aerobic bio-composting method to experimentally obtain optimal formulations of mixtures based on typical SS of Ukrainian STP with the addition of the most common and economical vegetable raw materials (wood chips) and recirculating active bio-compost. The criterion of the optimal formulation of raw materials for composting, and the established optimal composting regime were the results of the bio-indication of the obtained compost.

Conducting research in laboratory conditions allows minimizing influences on the process of bio-composting of various factors of external environment such as sharp differences in air temperature, waterlogging by atmospheric precipitations (at the realization of process in the open air).

2. Experimental part

The installation for bio-composting of organo-containing mixtures in laboratory conditions consists of a thermostated device brand TCP-0105, equipped with a tubular electric heater with a maximum power of 3.0 kW, temperature controller, mixer and thermocouple resistance. The volume of the working space of the thermostat is 250 dm^3. Internal dimensions of the thermostated capacity are 1080 × 810 × 320(280) mm. Overall dimensions (maximum) are 1200 × 900 × 550 mm. Inside the thermostatic device, there are four identical containers (standard plastic buckets with a nominal volume of 20 dm^3) partially filled with the investigated raw materials for composting.

The thermostated container is installed in the frame of the installation and covered with a special fastener for fixing the tanks with the studied substrates in the submerged position. In addition to the heating element and the mixer, a platinum resistance thermocouple is installed on top, which is electrically connected to the regulator. Automatic maintenance of the set temperature of water in the thermostat is carried out using the temperature regulator by change of the power given on a heater of the thermostated container. A platinum resistance thermocouple is connected to the regulator input and a triac to the output. A mixer, impeller mounted on the axis of the motor, serves to equalize the temperature field in the tank.

Temperature and humidity sensors are installed in the inner part of the tank lids. Sensors are connected by a cable with a digital eight-channel temperature and humidity meter VTV 118-4 (four channels for temperature and humidity). Temperature measurements in the thermostat are performed using a built-in temperature controller with a resistance thermocouple. The thermostat controller TCP-0105 has a digital display and buttons for setting the required values of water temperature in the thermostat vessel.

The aerobic composting experiment has been performed for 60 days in four plastic bioreactors with a capacity of 20 dm^3 each, which are tightly closed with lids. The initial volume of compost mixtures in each bioreactor is 12 dm^3, which is 60 % of their nominal volume (Fig. 1).

For aeration, the compost in the reactors was stirred vigorously once a day for 20 s. Temperature measurements of compost mixtures were performed once a day immediately after measuring the composition of the gas mixture by inserting the thermometer inside the mixture at the same depth from the bottom of the bioreactor.

Automatic maintenance of the set temperature of water in the thermostat is carried out using the temperature regulator by change of the power supplied to the heater of the thermostated container. A platinum resistance thermocouple is connected to the regulator input and a triac to the output. A mixer, impeller mounted on the axis of the motor, serves to equalize the temperature field in the tank.

To avoid a rapid decrease in temperature observed in small-volume reactors (Mason et al., 2004), the specified temperature was set to implement the thermophilic composting regime simulating the corresponding temperature dynamics inside the full-scale compost pile. The thermophilic regime of bio-composting lasted for 5–7 days, which is enough to destroy most pathogens, and then the temperature was gradually reduced. The temperature control procedure makes it possible to model the thermodynamic regime of the composting process, which will determine many other parameters of composting such as humidity, biological activity, and dynamics of microorganisms population (DSTU ISO 11269-2:2002, 2004).

Fig. 1. General view of the installation

The chemical composition of gas in bioreactors was measured once a day using a five-component gas detector-analyzer DOZOR-S-M-5, which allows determining the content of five gases in the air: oxygen (O_2), methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) and hydrogen sulfide (H_2S). To determine the oxygen content, its minimum value was recorded in bioreactors to ensure the necessary conditions for aerobic composting. It is considered that for the composting process, the oxygen concentration should be within 15–20 %. Sufficient aeration at the early stage of composting reduces the time of the process, which leads to the oxidation of carbon (C) to carbon dioxide (CO_2) and reduced methane emissions (Awasthi et al., 2014). The value of carbon dioxide was recorded at the maximum during the measurement.

Determination of the quality of the growth substrate was performed by the generally accepted method (DSTU ISO 11269-1:2004; Horova et al., 2008). One of the most promising crops was chosen for bio-indication research – Perennial fenugreek (Lolium perenne), which belongs to Category 1 – monocotyledonous plants and can be used for reclamation of man-made disturbed lands. Before the study the seed germination energy of each crop was analyzed and determined. Twenty identical seeds of the selected species were planted in each vessel. The percentage of seed germination relative to the average germination in the control vessels was calculated for each iteration in each variant. The root length of each plant was measured, and the average root length was determined for each studied growth substrate. Statistical analysis was used to determine the least significant discrepancies between control and test concentrations.

During the study, the dark gray podzolic soil was used as a control environment, to which fresh sewage sludge was added in the ratio (%) of 0; 30; 40; 50; 60; 70. Also, a natural sorbent – zeolite was added in the same substrate in the amount (%) of 0; 5; 10; 15.

The created substrate was poured into a 500 ml container and 20 fenugreek seeds were planted (90–95 % germination). The experiments were conducted in quadruplicate iteration to obtain reliable data. The laboratory maintained constant humidity (55–60 %), temperature (23–25 °C) and lighting (4 phytolamps with the light output of 1400 Lm). Irrigation of the test samples was carried out by drip irrigation daily depending on evaporation and was 5–7 ml /day for each test sample. During the experiment, observations were made on such indicators as time of emergence of sprouts, their number per day, total germination, and measurement of stem length; photos of samples were taken.

3. Results and Discussion

The criterion for the optimal composition of the raw material mixture for composting is the study of bio-indication on the obtained mixtures. Therefore, we used the following sequence to establish the optimal composition of the raw material mixture for composting and composting modes. Composting of four model mixtures, whose composition is given below, was performed on the bio-composting installation described above. During composting, the maximum possible number of process implementation parameters was analyzed. After that, bio-indication studies of the obtained composts were performed. For the best variant of bio-indication, the analysis of parameters of composting process realization was carried out.

As the main target raw materials for the development of model mixtures were used:

1. Sewage sludge.

– mechanically dehydrated “freshly selected” SS (SS_{fs}) after centrifugation of the mixture of raw sludge and excess activated sludge in the mechanical dehydration plant of Lviv STP$

– “old” (2–3 years old) SS (SS_o) selected on the existing sludge site of Lviv STP.

2. Wood chips obtained by mechanical crushing of wood waste at the site of bio-composting of organic waste of LCP “Green City” of the Lviv City Council were used as vegetable filler in all studied mixtures.

3. Recirculating, active, about two weeks old bio-compost was used in all the studied compositions selected from the middle part of the compost piles of the bio-composting station of LCP “Green City” to accelerate the development of the bio-composting process.

Four different mixtures of raw materials were prepared for laboratory composting: three mixtures (No. 1 – No. 3) with different volume fractions of SS and mixture No. 4 – control mixture of active compost. The planning of mixtures composition No. 1 – No. 3 was based on the recommendation of DSTU 8727: 2017 (p. 8.6) that in the case of using sawdust as a filler, the volume ratio of “filler: SS” is from 0.5:1.0 to 1.5:1.0 in summer and from 1:1 to 2.0–3.0:1.0 in winter (Rynk, 1992). It is necessary to use fillers to obtain high-quality compost. (Bernal et al., 2009). As a filler in their study Zhou et al. (2014) use wood chips to provide lignin useful for the formation of humic substances during composting. Scientists indicate the effectiveness of joint composting of manure with rice straw (Zhou et al., 2015) such composting ensures a balance of nutrients for microorganisms, as rice straw compensates the high density and moisture content during the composting process. Absorption of excess moisture and provision of the required porosity for better aeration in the compost mass is reported by Maulini-Duran et al. (2013). Meng, et al. (2016) note that the combined addition of mushroom substrate and wheat straw significantly improves compost quality and plant germination index, in particular reduced NH3 emissions by 21.9 %.

In this laboratory study, in the first approximation, the integer values of the ratio of the volumes of the filler (wood chips) and SS were accepted, namely two compositions with a ratio of 1:1 and one mixture of 2:1. To identify the impact of old SS on the bio-composting process in one of the mixtures with the ratio of "wood chips: SS" = 1:1 (mixture No. 3) half of the sediment volume was "freshly selected" SS, and the other half – "old" SS. For equality of starting conditions in the implementation of the bio-composting process in the laboratory, the initial volume of all mixtures before composting was the same and amounted to W_0 = 12 dm^3.

The humidity of raw material mixtures was determined by calculation based on the results of analytical laboratory determination of the humidity of all four components: "freshly selected" and "old" SS, wood chips and active bio-compost. The actual content of free moisture in the substrates was determined by measuring the weight loss and drying the samples in a thermostat brand TC-80 M °C at a temperature of 68 °C for one day. The volume fractions of components in mixtures No. 1 – No. 4 and their humidity are given in Table. 1.

Table 1

Volume fractions of components in the raw material mixture

Mixture number	SS_{fs}, %	SS_o, %	wood chips, %	active compost, %	Humidity of the mixture, % weight.
1	25	0	50	25	62.2
2	33.3	0	33.3	33.4	66.2
3	16.7	16.7	33.3	33.3	66.2
4	0	0	0	100	60.0

All mixtures were thoroughly mixed to homogenize their structure and intensify the composting 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 bio-composting process are given in 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 et al., 2015; Rynk, 1992):

– carbon and nitrogen content in SS is 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 is 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 bio-composting plant are estimated at 300 g/kg of dry substance and 20 g/kg of dry substance, respectively (C/N = 15).

Table 2

Estimated ratios of the mass content of carbon and nitrogen (C/N) in the raw material mixtures

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

Bio-composting of raw mixtures was performed according to the method described above. After the completion of the bio-composting process, the obtained compost was used for bio-indication studies, which were performed according to the method described above. During the study, ready-made composts were used, to which natural sorbent (zeolite) was added in the amount (%) of 0; 2.5; 5; 7.5.

The results of the bio-indication study showed that in the case of adding to the substrate natural sorbent – zeolite in the amount of 5 and 7.5 %, there is a positive effect on the germination of bio-indicator plants. The best germination rates were observed for compost No. 1 with zeolite additives and were 100 and 87 %, respectively. For compost No. 2, in samples with a zeolite content of 5 %, the average value of germination was 93 %. The average height of ryegrass stem for composts No. 1, 2 and 3 with sorbent content is higher than in these samples with sorbent content 0 % by 43 % (sorbent content 7.5 %), 6 % (sorbent content 2.5 %) and 9.7 % sorbent content 7.5 %), respectively. As noted by Tiquia and Hodgkiss (1996) a plant germination index greater than 80 % percent indicates mature and phytotoxic free compost. The average weight of one plant in compost No. 3 in samples with sorbent content of 2.5 % and 5 % is higher compared to the control variant (dark grey podzolic soil) by 23 and 63 %, respectively. The average weight of one stem in composts No. 3 and 4 with a sorbent content of 5 % is greater than the control by 11.1 %. The average value of the root length in compost No. 3 in the sample with a sorbent content of 5 % is 5.4 times more than the control variant with a sorbent content of 5 %.

Thus, based on the obtained data, we can state that the optimal universal component for creating a growth substrate is compost No. 3 (containing a mixture of “freshly selected” and “old” SS). Root systemin of the plants grown on it is not so developed, which allows adapting to various environmental factors and in combination with a small proportion of natural sorbents can be effective for the reclamation of landfills, which minimizes the need to use a fertile soil layer. Based on this result, the modes of the composting carried out earlier were further analyzed for compost No. 3, the raw material composition of which was as follows: SS_{fs} – 16.7 %; SS_o – 16.7 %; wood chips – 33.3 %; active compost – 33.3 %. The humidity of the raw material mixture before the start of bio-composting was 66.2 %.

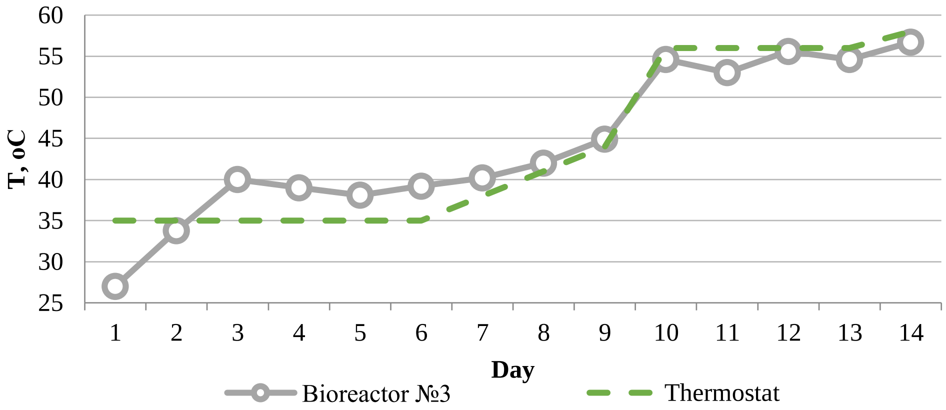
Temperature is one of the main parameters of the anaerobic composting process, which characterizes the intensity of decomposition of organic matter by aerobic microorganisms and is subject to monitoring. The initial temperature of bio-composting was 27 °C. Fig. 2 shows the temperature graph of the studied compost mixture. The study started at a water temperature in a thermostated tank of 35 °C, which corresponds to the average temperature of mesophilic aerobic composting.

At the beginning of the experiment, the temperature of the compost mixture was significantly lower than the temperature in the thermostat, but on the second day of the research, the temperature was higher than the water temperature in the thermostat, which is evidence of rapid activation of processes of decomposition of organic raw materials by aerobic microorganisms accompanied by intense local heat release. For example, two days after the start of a series of studies, the temperature inside the compost mixture was 40,0 °C which corresponds to a significant positive temperature difference ΔT in the mixture and $\Delta T = +5.0$ °C, which is indirect evidence that the most intense phase of aerobic composting in control active compost has already taken place in natural conditions in the piles of the bio-composting station. On the seventh day of the research, the water temperature in a thermostated tank was increased, reproducing the gradual transition of the composting process from mesophilic to the thermophilic mode in laboratory thermostated conditions. Starting from the 13th day, the temperature of the compost mixture stabilized at 2–5 degrees less than the water temperature in the thermostat, which indicates a decrease in the intensity of biodegradation and the transition to the stage of maturation of the compost mixture.

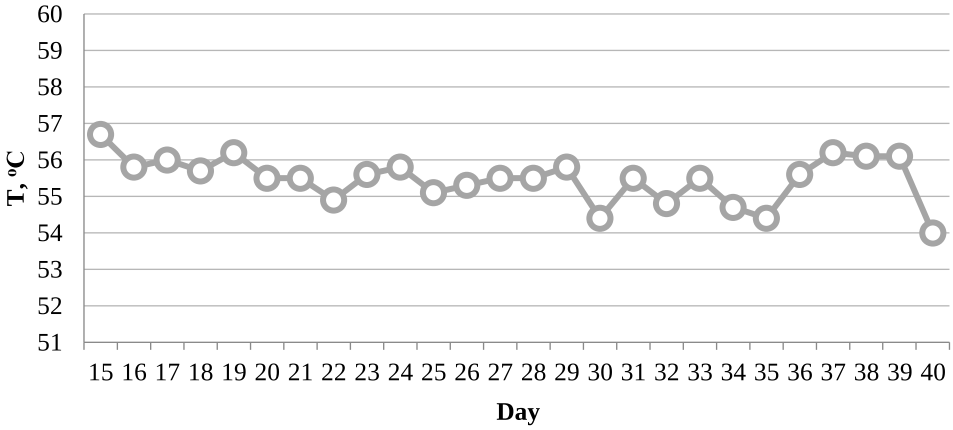
The minimum concentration of O_2 in bio-compost mixtures decreased slightly in the first week (Fig. 3). Later, some fluctuations in oxygen concentration were observed, which is probably due to the non-stationary period of formation of the bio-compost process. Subsequently, starting from the 15th day of the study, the oxygen concentration stabilized and became constant.

Since CO_2 is the main gas formed due to microbial degradation of organic matter, the rate of

CO_2 emissions reflects the rate of decomposition of organic matter and microbial activity in the process of anaerobic composting of organo-containing mixtures (Awasthi et al., 2014). The change in CO_2 content (% vol.) inside the bioreactor is presented in Fig. 4. The maximum CO_2 content in the bioreactor at the level of 6.7 % vol. was observed in the period from 1 to 8 days of the research. From the 15th day, stable values of CO_2 content in the bioreactor were observed in the range of 0.5–1.5 % vol. of CO_2.



a)



b)

Fig. 2. Change in temperature of compost mixtures in the bioreactor: a) from 1 to 14 days; b) from 15 to 40 days

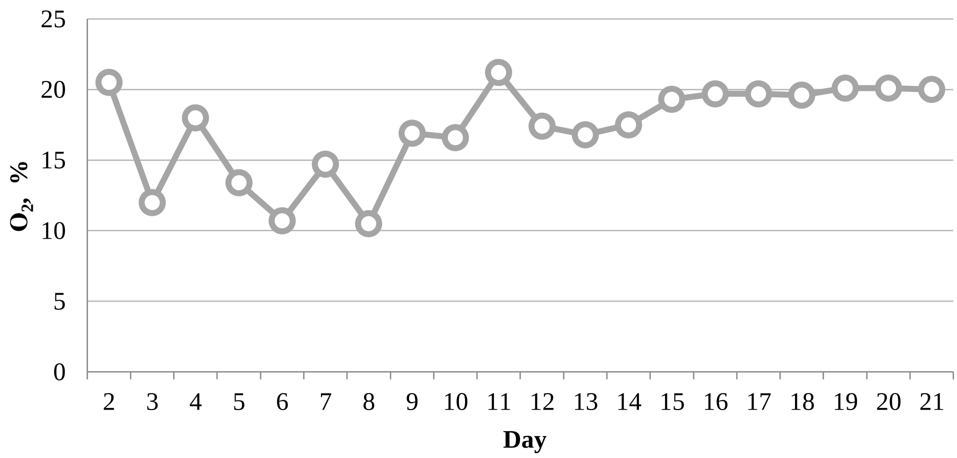


Fig. 3. Changes in the time of the volume fraction of oxygen in the gas environment of the bioreactor

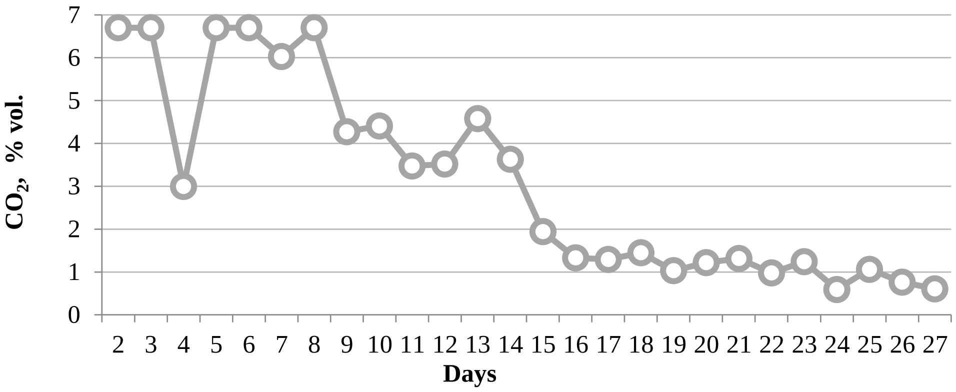


Fig. 4. Changes in CO_2 content inside the bioreactor

Moisture content is usually reduced due to a combination of high levels of temperature and aeration during the thermophilic phase. The initial moisture content (68 % of the wet mass) decreased, therefore, the practical method was used to determine the level of water evaporation in bioreactors (drying of samples in a thermostat), and periodic watering was carried out to maintain optimal humidity of the composting mixture.

4. Conclusion

1. The results of the study of the aerobic bio-composting of organo-containing mixtures in the laboratory proved the prospects of using sewage sludge as a raw material.
2. Based on the analysis of bio-indication data, we can state that the optimal universal component for creating a growth substrate is compost No. 3 (containing a mixture of “freshly selected” and “old” SS). The terrestrial parts of the plants grown on it are not so well-developed but have very branched root systems. This allows plants to adapt to various environmental factors and, in combination with a small proportion of natural sorbents, ensures the efficiency of landfill reclamation, which minimizes the need to use a fertile soil layer.
3. The analysis of changes in the parameters of the bio-indication process for compost of the established optimal composition (change in temperature, change in the volume fraction of oxygen and CO_2 content in the gaseous medium) was made, which makes it possible to develop recommendations for the implementation of the process in industrial conditions.

Acknowledgements

This research is supported by the National Research Foundation of Ukraine (Project 2020.02/0177 “Development of a complex technology for obtaining and using substrates based on organic waste and natural sorbents for the needs of biological reclamation and remediation of industrially disturbed lands”).

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