SLUDGE RECOVERY THROUGH COMPOSTING: CASE STUDY - CĂLĂRAȘI SEWAGE TREATMENT PLANT, ROMANIA

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Our actual context is reflected in the food chain increased demand worldwide, but at the same time is reflected also in the climate change which affects our chain of supply, meaning increase soil temperatures, lack of rain (drought) etc. On the other hand, our soil is drained of nutrients because soil is not resting between seasons. Having no more winters with abundant snow, agricultural fields are cultivated more than once during the year, with huge negative effects on the agricultural fields. Major changes must be considered, meaning that better soil management should be done. The first action required is to improve soil characteristics to serve the increased necessity of more food. There are natural ways to solve these challenges, and one of them is to create compost from the organic waste which humankind produces. In this way, we ensure a healthier balance, not using natural resources or chemical products and we introduce the organic waste back into the bio circular economy strategy that we have across Europe. The treatment of biowaste through composting is the most widespread biological method of organic waste treatment in the European Union. Biowaste composting plays an important role in the transition to a circular economy. The final product (compost), which is used in agriculture as a soil amendment or fertilizer, needs to be of extremely high quality to complete the loop of biowaste treated by composting. Under these conditions, the current study focuses on the potential for producing compost by mixing green waste with sewage treatment plant sludge. Within the parameters of the present experimental study, 75 cubic meters of compost were produced from 200 cubic meters of biowaste (sludge: green waste, 1:2 ratio). Due to the lack of specific standards and procedures (guidelines) for obtaining and validating high-quality compost that can be used in agriculture in the context of Romanian legislation in the field (Law 181/2020), reference values of physico-chemical parameters from regulations in force in various UE states were taken into consideration for the compost quality evaluation.

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Keywords: organic waste, compost, heavy metals, biowaste, circular economy

1. Introduction

About 35% of the municipal waste produced in the EU is classified as biowaste, which is an important category with significant recovery potential (material and/or energy recovery). When using biowaste as a resource, separate collection of the waste is required. It takes time and effort to put in place an effective system for collecting biowaste separately. Therefore, to incorporate the biowaste strategy into the waste and circular economy strategies, a comprehensive policy framework is required.

The Waste Framework Directive, along with its ensuing modifications and revisions, establishes new regulations regarding the distinct collection of biowaste. Therefore, the member states of the European Union are required to make sure that biowaste is either collected separately or recycled at the source (by composting, for example) by December 31, 2023. Furthermore, as of January 1, 2027, compost made from mixed municipal waste will not be included in achieving the municipal waste recycling goal. Only when the separately collected biowaste is appropriately treated can the potential advantages of this approach be realized. Treatment facilities must therefore be planned in accordance with the volume of biowaste produced and the unique collection system used.

In Romania, the separate collection of biodegradable waste at the source is just at the beginning [1],[3]. Due to the current legislative changes in the field of waste [4], [5], both natural and legal persons must significantly reduce the amount of generated waste, separating the biodegradable waste from recyclable and mixed waste [6], [7]. At the level of each county from Romania, organic waste can represent between 45-65% of the total waste that is generated. In most cases, they end up in landfills, where they produce methane, a gas that is 20 times more dangerous than carbon dioxide. The need to take measures that reduce the gas emissions with the greenhouse effect to mitigate global climate changes but also to avoid pollution led to the need for separate collection and treatment/recovery of organic waste [2]. The operators of municipal sewage treatment plants are constantly looking for new, innovative, and, at the same time, sustainable solutions to treat the sludge resulting from the sewage treatment process [16]. At the same time, operators of waste landfills also use organic waste treatment systems to capitalize on them by creating fertilizers or by producing energy [22]. In this synergy of ideas, at the level of the Călărași municipality, it was decided to recover organic waste through composting by using it as input material sludge from the local treatment plant and green waste collected by the local sanitation company. In this regard, a mobile composting installation with a semi-permeable membrane and positive forced aeration was used. Herein we present the results obtained after carrying out some composting tests that took place in a location made available by the Călărași municipality.

2. Material and methods

2.1 Experimental setup: the composting system

During the experimental activities, the following equipment was used:

Tractor. With its support, sludge from the Călărași municipality's sewage treatment plant and green waste from the municipality's parks and tree-clearing operations were gathered.

Shredder. The branches were chopped to bring them to a size between 5 and 15 cm. Cut branches are essential in the composting process. They create space in the mass of the mixture of green waste and sludge from the municipal sewage treatment plant, space needed for air to penetrate the entire mass of waste to be composted (Fig. 1).

Fig. 1. Shredder for green waste (original - Inoveco)

Bulldozer. It was used to load the shredder's feed hopper, being used at the same time for the mixing of green waste shredding and sludge. Later, it transported the mixture of organic waste to the **composting** platform and placed it in the furrow (Fig. 2).

Fig. 2. Bulldozer (original - Inoveco)

The **composting system** consists of a SCADA system, a computer, temperature, oxygen, and pressure sensors, a ventilation system, a semi-permeable membrane, perforated pipes in the upper third, and a generator (Fig. 3 and Fig. 4), provided by the company Inoveco SRL. This composting system is used for a total quantity of biowaste of 200 cubic meters. Depending on the recipes and the types of biowaste mixtures, this mobile unit can provide a quantity of 60-90 cubic meters of compost. The rest of the material is going to be used in the next batch of biowaste as structural material to be transformed into compost.

Fig. 3. SCADA system, fan, and connections (original - Inoveco)

Fig. 4. Semi-permeable membrane and automatically controlled forced aeration system (original - Inoveco)

Sieve. At the end of the composting process, respectively, the completion of phase 2 of composting, a sieve of 2 cm is used (Fig. 5). The material, which has a diameter smaller than 2 cm, was placed in a pile and left to mature in "quieting process". A sample was taken from this material and was sent for testing. Material larger than 2 cm was used as the structural material for a new batch of organic waste to be composted.

Fig. 5. Screening of the composted material (original - Inoveco)

2.2 Experimental development

Description of the phases of the composting process

During the composting process, organic substances undergo transformations that are represented by two sequential phases: decomposition and maturation [21].

The mobile composting unit with a semi-permeable membrane and forced aeration is designed to compost organic waste based on composting science. In this case study, the duration of the treatment process under the membrane was 42 days with an intermediate return (after the intensive decomposition phase of 28 days) [20].

The mobile unit is equipped with a tarpaulin containing a semi-permeable membrane, a positive aeration system [24] (fan, perforated HPDE pipes, flexible tubes, and fittings), and a SCADA system for monitoring and controlling the temperature and oxygen from the pile of organic waste (includes a computer with licensed software). The mobile unit has a power supply connection (380V, 50Hz, 16A) and a data subscription (purchased from a mobile phone service provider). On the opposite side of the control and aeration system container, a maneuver space is provided to be able to extract the aeration pipes from the pile (the extraction was done with the front loader).

During the treatment, the installation needs only monitoring the process through the remote software application. Any adjustments are made from the same application and two people are needed for the membrane installation/uninstallation.

The input material

The organic raw material used in this case study was sludge from the city sewage treatment plant (SEAU) and green waste collected from the green area of the city, as shown in Fig. 7 and Fig. 8, with a ratio 1:2, sludge: green waste. The green waste was chopped with a chopper like the one in Fig. no. 1. The size of the wood chips is around 5-10 cm or smaller. The green waste was chosen so that it was biologically active and did not have to contain soil, charred wood, or chemically treated timber/wood [8], [11]. To obtain the necessary raw material, according to the specifications of the Gore operating manual [19], a pre-treatment step was necessary, in which appropriate amounts of each ingredient had to be crushed and mixed before entering into the composting process.

Fig. 6. Example of SEAU sludge (original - Inoveco)

Fig. 7. Green waste collected from parks and gardens (original - Inoveco)

The mixture used in the composting process was properly prepared for composting in the mobile installation. The input monitored parameters were: Carbon/Nitrogen initial ratio (C:N) of 25-35:1; Moisture content of 55% - 65%; Optimum porosity for a uniform air distribution and the final density after pre-treatment of approximately 0.65 t/m³. At the same time, the mobile composting system [23] was installed (positioning of the SCADA system, positioning of pipes, etc.) according to Fig. 3.

After the mixture was made, it was transported and placed in the form of a prism over the aeration pipes, previously starting the blower connected to the pipes. After the stack was completed, it was sprinkled with water to reach an optimal moisture content for the composting process, which was measured with a moisture meter Afterwards, the semi-permeable membrane was placed over the organic waste prism in the mixture and the system was connected to the SCADA software. Thus, Phase 1 of the composting, process called the above, Decomposition, lasted 4 weeks (Fig. 8).

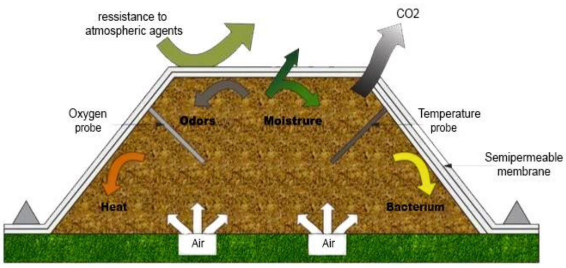

Fig. 8. Schematic diagram of the properly aerated areas (positive aeration) (Inoveco photo)

Fig. 8 presents how the moisture content is self-maintained by the recirculation under the membrane. The heat inside the pile evaporates the water which migrates through the pile to the above layers until it reaches the lower part of the membrane. When it reaches the membrane, it falls into the pile due to condensation. Therefore, the moisture content is slightly decreasing during the 4 weeks of intensive organic waste decomposition, a process that is expected and it is in optimum parameters, according to the operation manual of the mobile unit of composting [19].

The furrow was turned at the end of phase 1 of 28 days. The membrane was removed, and the pipes were withdrawn and repositioned next to the initial stack, with the help of a bulldozer. Fig. 9, illustrates colonies of fungi developed following the decomposition process of green waste, similar to other case studies with the same type of waste [10]. The material from Phase 1, aerated with the bulldozer, was placed over the repositioned aeration pipes (Fig. 10). This intermediate stage in the composting process is indispensable during compost-making [15] to facilitate the cooling of the substrate and to keep the oxygen level at the necessary values or even higher for the activity of aerobic microorganisms. The optimal range for the oxygen level is between 5% - 15%.

Fig. 9. Development of mushroom colonies in Phase 1 of composting (original - Inoveco)

Fig. 10. Turning the stack after the first 28 days (original - Inoveco)

Phase 2, of 14 days, began with covering, again, the newly formed furrow with the semi-permeable membrane and starting the SCADA software. At the end of Phase 2, the membrane was removed, and the mixture was moved to a free area to mature for another 14 days. After the maturing period, it was sieved using a mobile sieve. The sieve has apertures of 2 cm. A sample was taken from the fraction smaller than 2 cm to test the quality of the compost. The fraction larger than 2 cm was removed to be reused as a structural material in a new composting process. The entire composting process was carried out with the mobile composting installation with a semi-permeable membrane and positively forced aeration.

After the completion of Phase 2 of composting, the unscreened compost has the appearance of flower soil but with variable dimensions between 0.1 cm and 6 cm. Fig. 11 and Fig. 12 present a mature compost with dimensions between 0.1 and 2 cm, obtained by sieving. Sifting was carried out with the support of a mobile rotary sieve.

Fig. 11. Unscreened compost obtained after 56 days of treatment (original - Inoveco)

Fig. 12 The sieved compost obtained after 56 days of treatment (original - Inoveco)

The screen was fed through a loading hopper, which in turn was fed by another machine (bulldozer, front loader) - Fig. 13. The conveyor belt related to the machine's hopper transferred the content to the cylinder of the sorting site. The cylinder (drum) of the sorting sieve was set in motion by a hydraulic motor and was fixed on bearings (they are built to also operate in very heavy conditions). The movement was transmitted through a solid transmission chain. The speed of the conveyor belt, related to the loading hopper, could be adjusted within the desired limits, taking into account the loading speed. The machinery's protection system acted in case of any deviation of the operating parameters by stopping the diesel engine. The sieve used in this experiment had a mesh size of 20 mm. Throughout the sieving process, it was cleaned by a rotating brush that was positioned along the entire length of the sorting sieve cylinder. It should be specified that the positioning of the unloading belts in the working or transport position was done manually by two winches.

Fig. 13 Mobile rotary sieve for separation between fractions (original - Inoveco)

3. Results and discussion

Following the composting process, samples were sent to an independent laboratory by the operator although at this moment, at the legislative level, the technical norms regarding the laboratory analysis that must be carried out to prove the achievement of a quality compost [13], [14] are not published. To be able to determine the quality of the compost, the Austrian compost legislation (the most advanced in this field in Europe) was used as a reference. According to the performed analysis, the determined parameters are presented in the next tables:

Table 1

Characteristics of the compost after the field experiment

Parameters	Raw material	Intermediary phase	Final phase	U.M.	Analytical Methods
Total moisture	58.4	33.7	22.4	%	SR EN 15934: 2013
Dry substance	41.6	66.3	77.6	%	SR EN 15934: 2013
Organic Carbon	24.66	12.24	10.48	% s.u.	EN 15936: 2013
Total Nitrogen	2.51	1.38	1.27	% s.u.	SR EN 16168: 2013
Bulk density	1003	546	668	Kg/m^3	EN ISO 17828: 2016
Electrical conductivity	1384	1835	1928	µS/cm	ISO 11265 + A1:1998
Loss of calcination (organic substance)	45.47	29.59	25.49	% s.u.	EN 15935: 2013
Salmonella spp	Not detected	Not detected	Not detecte d	Detected/not detected/mass	EPA 1682:2006 POL-16 Ed.2 RO
Escherischia coli	26*10^5	528	15	Probable No./gsu	EPA 1680

Parameters	Raw material	Intermediary phase	Final phase	U.M.	Analytical Methods
Enterococci (faecal streptococci)	$17*10^5$	73500	1	Probable No./gsu	Methodological guide ICIM chapter IV.4 POL-16 Ed.2 RO
Cd	1.15	0.77	0.84	mg/kg s.u.	SR EN 16171:2017 SR EN ISO 54321:2021
Total Cr	110	29.06	144	mg/kg s.u.	
Cr^{VI}	<0.05	<0.05	<0.05	mg/kg s.u.	SR EN ISO 11083:1998
Cu	103.9	79.97	74.26	mg/kg s.u.	SR EN 16171:2017 SR EN ISO 54321:2021
Hg	<0.30	<0.30	<0.30	mg/kg s.u.	
Ni	57.17	27.18	71.39	mg/kg s.u.	
Pb	4.23	36.39	37.85	mg/kg s.u.	
Zn	550	420	213	mg/kg s.u.	
Total As	5.46	8.82	5.38	mg/kg s.u.	
P_2O_5	23950	23120	17580	mg/kg s.u.	EN 15309: 2007
K_2O	12530	20120	20640	mg/kg s.u.	EN 15309: 2007
CaO	45250	55580	54000	mg/kg s.u.	EN 15309: 2007
MgO	13000	17380	17790	mg/kg s.u.	EN 15309: 2007
Na_2O	16070	14080	14060	mg/kg s.u.	EN 15309: 2007
SO_3	2.3	1.43	1.18	%s.u	EN 15309: 2007
Soluble salts	0.17	2.26	0.95	mg/kg s.u.	STAS 7184/7-87
pH	6.2	7.1	6.9	pH units	EN 15933: 2013

Physico-chemical and microbiological properties

Table 2

Comparing heavy metals concentrations in raw material and in compost with the values from in force regulation

	Cd	Cr totally	Cr^{VI}	Cu	Hg	Ni	Pb	Zn	As totally
	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.	mg/kg s.u.
The composting test									
Raw material	1.15	110	<0.05	103.9	<0.30	57.17	4.23	550	5.46
Intermediate results	0.77	29,06	<0.05	79.97	<0.30	27.18	36.39	420	8.82
Final results	0.84	144	<0.05	74.26	<0.30	71.39	37.85	213	5.38
Limits of heavy metals for the use of sludge in agriculture									

Directive 86/278/EEC transposed into Romanian legislation by Order no. 344/2004	20–40	-	-	1000–1750	16–25	300–400	750–1200	2500–4000	-
Compost ordinance applicable in Austria (lower)	2	50	-	300	2	100	400	1500	-
Compost ordinance applicable in Austria (upper)	10	500	-	500	10	100	500	2000	-
France, conditions imposed by the NF standard U44-051	20	1000		1000	10	200	800	3000	-

Table 3

Microbiological parameters							
		Salmonella spp	Escherischia coli	Enterococci (faecal streptococci)			
	UM	Detected/not detected /mass	Probable No. /gsu	Probable No. /gsu			
The composting test	Initial results	Not detected	26*10^5	17*10^5			
	Intermediate results	Not detected	528	73500			
	Final results	Not detected	15	1			
Analysis results for the determination of nutritional elements							
		P_2O_5	P_2O_5 (calculated)	K_2O	K_2O (calculated)	Organic Carbon	Total Nitrogen

The composting test	UM	mg/kg s.u.	%s.u	mg/kg s.u.	%s.u	% s.u.	% s.u.
	Final results (compost)	17580	1,758	20640	2,064	10,48	1,27
	NPK dose at 1 ton compost s.u.	N = 13 kg	P = 18 kg	K = 21 kg			

Table 4

Physical parameters of compost

Total moisture	**Dry substance**	**Bulk density**	**Electrical conductivity**	**Calcination loss (organic substance)**	**Soluble salts**	**pH**
%	%	Kg/m^3	μS/cm	% s.u.	mg/kg s.u.	pH units
22.40	77.6	668	1928	25.49	0.95	6,9

* These parameters, in accordance with the quality rules, must be declared mandatory or optional and must appear on the product label

Considering the test results from the accredited laboratory, for the chemical and physical parameters included in Table 1, the compost samples that have been analyzed meet the criteria imposed by the Order 344/2004, which are the Technical Norms on the use of sludge in agriculture. It is clearly stipulated that only treated sludge can be used in soils that cultivate plants for human use. Moreover, the levels of metal concentrations identified in the obtained compost were below the limits provided in the specific legislation of some EU states (see Table 2). It was necessary to use such references since, in the context of national legislation in the field (Law 181/2020 [7]), there are no specific standards and procedures (guidelines) that lead to obtaining and validating a quality compost which can be used in agriculture.

Regarding the C:N ratio in the initial mixture (24.66), this was slightly lower than the optimal one recommended (according to data from the literature, it must be between 25 and 30). This value could be explained by the initial mixture's slightly higher intake of wood chips, which may have lowered the C:N ratio. About the content of the main nutrients: nitrogen (N), phosphorus pentaoxide (P2O5), or potassium oxide (K2O), the sum of the concentrations of the respective nutrients represents approximately 5% of the mass (1.27% total N; 1.75%P2O5; 2.06%K2O). It was observed also that electrical conductivity has an increasing evolution, which is a benefit, electrical conductivity being an indication of nutrient availability.

Considering the restrictions imposed by the extracted legislation that we have set out above, we noted that the limits for heavy metals present in compost are below those imposed both by Order 344/2004 and by Council Directive 86/1986 both for sludge as well as for the soil on which the recycled sludge can be applied. The obtained material is sanitized. Salmonella was not present in any of the phases of the process and the Escherichia coli, while Enterococci (fecal streptococci) was evidenced at a low level in samples taken from the initial mixture and in the final phase. This also satisfies the rigor imposed by the fertilizer regulation, 1009/2019 [17].

According to the on-site measurements, out of 200 cubic meters of biowaste, there were obtained 75 cubic meters of compost. At national level, in Romania, there are produced more than 100.000 tons per year of sludge. The actual legislation permits that the sludge to be deposited in landfills, which creates a number of important disadvantages like filling up quicklier the landfills, creating carbon dioxide due to fermentation in open air, bad smells, affecting the population, etc. Using the compost method to reduce the impact of the sludge produced in wastewater treatment plants, min 30% up to 60% compost from the total quantity of sludge at nation level can be obtained.

4. Conclusions

The current experimental study evidenced that compost can be obtained from green waste mixed with sludge from the sewage treatment plant [18], [20] within 365 days/year. Following 56 days of treatment, the compost smells earthy and pleasant like freshly excavated soil. The achieved results showed that, undergoing the 56-day treatment, from the organic mixture of wood chips and sewage sludge, it was obtained a recoverable product (compost) that can be used as an organic fertilizer on various land surfaces such as green spaces, recreational areas, roads' shoulder, filling material, waste landfills covering and so on.

Sludge is not waste; sludge is a resource that can be used to generate compost, but it must meet certain requirements in order to safeguard both human health and the environment. Thus, the quantity of waste produced can be reduced by using an industrial composting facility by converting it into compost, an organic fertilizer that is essential for enhancing soil quality [12]. At the same time, it is important to remember that the nutritional needs of the plants must also be considered when using compost made from sludge.

Acknowledgments

This work was partially supported under contract no. 12/14.04.2022/SIMECPOP project financed by the Academy of Romanian Scientists.

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