Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. VI, 2017
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

SEWAGE SLUDGE COMPOSTING AND ITS AGRICULTURAL USE

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Abstract

In solid waste management, composting is defined as a controlled biological process which takes place under aerobic conditions and causes the production of simple and stable compounds in a solid substrate through the degradation of organic matter derived from animal and vegetative residues. Due to the concerns for public health and the environment, in several countries the term "composting" used in organic waste management has evolved over the years referring to the aerobic stabilization of source-separated organic matter. Sewage sludge, being a waste resulted from anthropic activities, is subject to waste regulations which prioritize their management options in order to reduce the negative environmental impacts, the ultimate option being considered the disposal into a landfill.
According to the waste management hierarchy, sewage sludge has to be improved whenever possible before final disposal. Waste water treatment, mainly domestic, results in the concentration and disposal of the materials from the treated wastewater. These concentrated residual materials in admixture with water from the sewage sludge. It contains a variety of dissolved or suspension compounds: with agronomic value (compounds with nitrogen, phosphorus, potassium, calcium, magnesium, silicates, alumina, organic matter, trace elements - boron, cobalt, selenium, iodine etc), with energy value (organic matter) and potential pollutants (heavy metals, volatile organic compounds, pathogenic organisms etc).
Composting sludge from sewage treatment plants represents an intensive activity and in the case of large sewage treatment plants, a large-scale activity requiring specific technologies, equipment and activities. This sludge treatment method from sewage treatment plants is an effective solution in order to significantly reduce the costs associated with disposal and also allows the production of excellent compost that can be sold for use as a natural product to improve the characteristics of soil.

***Key words**: composting, solid waste, sludge.*

INTRODUCTION

In solid waste management, composting is defined as a controlled biological process which takes place under aerobic conditions and causes the production of simple and stable compounds in a solid substrate through the degradation of organic matter derived from animal and vegetative residues. The solid product resulting from composting is characterized by relatively short molecular chains, a high degree of sanitization and is rich in humic compounds, making it useful for application to agricultural fields and for remaking the concentration of organic matters in soil (Metcalf & Eddy, 2003).
In the composting process, microorganisms use oxygen to convert organic matter into compost, producing in the same time carbon dioxide ($C0_2$), water, nitrate (NO_3), sulfate ($S0_4^{2-}$) and heat. This relationship can be generally represented by the following formula:

$$\text{Organic matter} + O_2 \rightarrow \text{compost} + CO_2 + H_2O + NO_3 + SO_4^{2-} + \text{heat}$$

Nowadays, composting is an interesting area from many points of view, such as:
- Environment-Ecology: By composting, organic matter derived from sludge from sewage treatment plants transforms into useful products for agriculture which are characterized by high content of nutrients, soil structuring properties and low phytotoxicity;
- Hygiene: During the process, high temperatures are reached consequently destroying pathogens and germs;
- Energy: The process uses the energy released by destroying the biochemical bonds in the organic matter (Chiumenti et al., 2005).

Due to the concerns for public health and the environment, in several countries the term "composting" used in organic waste management has evolved over the years referring to the aerobic stabilization of source-separated organic matter.

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Waste water treatment, mainly domestic, results in the concentration and disposal of the materials from the treated wastewater. These concentrated residual materials in admixture with water from the sewage sludge. It contains a variety of dissolved or suspension compounds:

- with agronomic value: compounds with nitrogen, phosphorus, potassium, calcium, magnesium, silicates, alumina, organic matter, trace elements - boron, cobalt, selenium, iodine, etc.
- with energy value: organic materials
- potential pollutants: heavy metals, volatile organic compounds, pathogenic organisms, etc (Directive 2008/105).

Sewage sludge, being a waste resulted from anthropic activities, is subject to waste regulations which prioritize their management options in order to reduce the negative environmental impacts, the ultimate option being considered the disposal into a landfill.

According to the waste management hierarchy, sewage sludge has to be improved whenever possible before final disposal. Figure 1 shows the pyramid of the management options hierarchy for the sewage sludge.

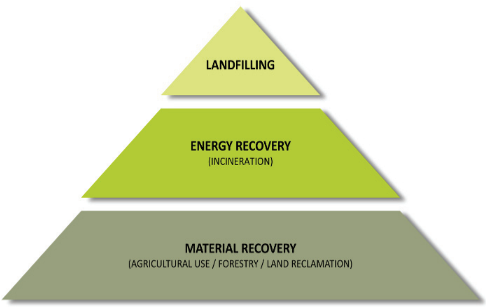

Figure 1. Options hierarchy

Following market research at European level, the development trends are:

– For the original Member States (EU12):
  - Sludge use in agriculture and incineration growth;
  - Differences between countries;
  - Reducing disposal at landfills.
– For the new Member States (EU15):
  - Short-term increase in storage at landfills;
  - Development of agricultural yield and studies for the application of incineration;
  - Sludge production increment from new and rehabilitated SEAU;
  - Anaerobic digestion - the most common treatment process.

In the figures 2, 3 and 4 can be seen the trends in the development for the main sludge management options.

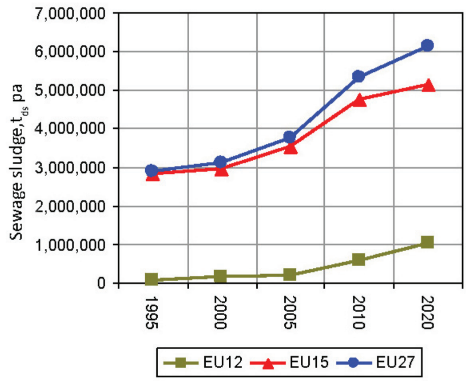

Figure 2. Agriculture

Note: The significant growth trend in both the original (EU12) and the new Member States (EU15), as qualitative restrictions increase, denotes the development and implementation of sludge recovery solutions.

The most convenient solution is composting with the addition of local energy material (which does not involve additional costs for the "manufacturer") and allows strict control of the C/N ratio.

Thus, composting is one of the main options for the sludge recovery.

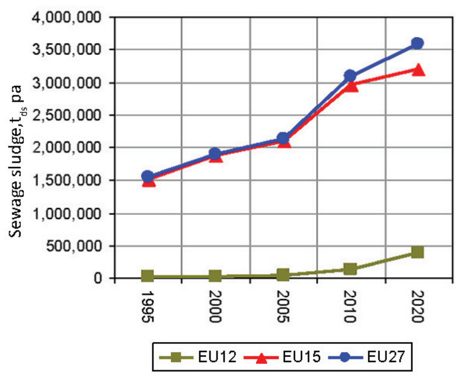

Figure 3. Incineration

Note: The growth trend is significant in both the original EU12 and the new Member States (EU15), given that the quantities processed and the processing trends are about half of the quantities intended for use in agriculture. Due to the high investment costs, the need for specialized labour force and advanced technology of the operational processes, correlated with the high CO_2 emissions in the new countries and especially in Romania, the trend of the growth for the fully incinerated sludge in the energy recovery process has a very slow evolution; in addition, most of the investments in the treatment plants have developed the anaerobic component with the energy recovery of the resulting biogas.

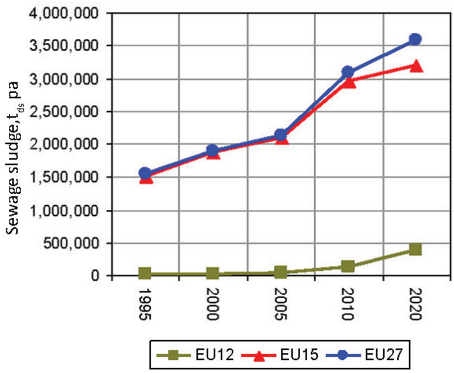

Figure 4. Disposal

The trend is a significant decrease for the original Members (EU12) and growth (doubling) for the newcomers (EU15), the maximum limit being 500,000 t_{DM}/year in 2022 (Directive 91/271).

If these values are cumulated at EU level, there is a decrease from 1,400,000 in 1995 to 1,000,000 in 2020 [t_{DM}/year] (Tables 1, 2).

After 2022, the downward trend is also reflected for the new members and is increasing at EU level (Directive 2006/118).

There is a significant upward trend in agricultural use, a trend that represents more than half of the total quantity, correlated with growth in energy recovery and sharply diminished of the sludge disposal (Trasca et al., 2011).

Table 1. - The synthesis of trends regarding the sludge management in EU

Type of use	Member State	Year / UM [Million t_{SU}] 1995	2000	2005	2010	2020
agriculture	old member	2.80	3.00	3.00	4.80	5.00
	new member	0.05	0.10	0.10	0.60	1.05
	Total	2.85	3.10	3.10	5.40	6.05
incineration	old member	1.50	1.90	2.10	3.00	3.20
	new member	0.00	0.00	0.05	0.20	0.45
	Total	1.50	1.90	2.15	3.20	3.65
landfill	old member	1.45	1.40	1.45	1.45	1.10
	new member	0.35	0.40	0.45	0.50	0.50
	Total	1.80	1.80	1.90	1.95	1.60
sludge manage-ment total	old member	5.75	6.30	6.55	9.25	9.30
	new member	0.40	0.50	0.60	1.30	2.00
	Grand total	6.15	6.80	7.15	10.55	11.30

Table 2. Percentage evolution of the main uses for sludge in the EU

Type of use	Level	Year 1995	2000	2005	2010	2020
agriculture	Total EU States	46.34%	45.59%	43.36%	51.18%	53.54%
incineration		24.39%	27.94%	30.07%	30.33%	32.30%
disposal		29.27%	26.47%	26.57%	18.48%	14.16%

Current state of the sewage sludge production and management in Romania (2014/2015) and the forecast for 2017-2025

Beneficial use, with the most practical and efficient means, avoiding, as much as possible, the disposal of sewage sludge into landfills in accordance with national and EU policy, is the responsibility of the wastewater treatment plant OPERATORS (Directive 1999/31).

They have the responsibility to develop medium and long-term strategies for the sludge improvement and to develop sludge markets.

Conditionality related to the sludge disposal and the development of opportunities for recovery:

- The physical capacity of the receptors, taking into account the constraints imposed by the environmental protection legislation and, on the other hand, by the
- Acceptance of potential beneficiaries to capitalize on them (landfill recovery,

energy recovery, landfilling and disposal on other specific areas (including "lagoons" for liquid sludge).

- The evolution of the sludge quantity due to the continuous production process, result of the investments made and in progress for the SEAU rehabilitation and construction, following the necessity to comply with EU legislation (Directive 86/278).
- The evolution of the sewage sludge amount by region.

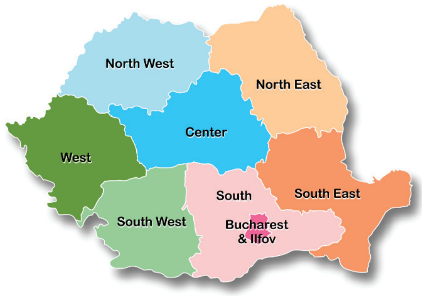

Figure 5. Map of the development regions

Table 3. Table with the prognosis of sewage sludge evolution (Order 344/2004)

Region	Component counties	UM [t_{SU}]					
		2014	2018	Interval I	2025	Interval II	Interval III
1	2	3	4	5 =4-3	6	7=6-4	8=6-3
NE	Bacau, Botosani, Iasi, Neamt, Suceava, Vaslui	28,000	70,000	42,000	68,500	-1,500	40,500
SE	Braila, Buzau, Constanta, Galati, Tulcea, Vrancea	23,900	83,100	59,200	81,900	-1,200	58,000
S	Arges, Prahova, Dambovita, Teleorman, Giurgiu, Ialomita, Calarasi	37,800	92,700	54,900	91,600	-1,100	53,800
SV	Dolj, Gorj, Mehedinti, Olt, Valcea	30,000	81,500	51,500	79,500	-2,000	49,500
V	Arad, Caras-Severin, Hunedoara, Timis	17,200	59,400	42,200	57,400	-2,000	40,200
NV	Bihor, Bistrita-Nasaud, Cluj, Maramures, Satu Mare, Salaj	10,100	40,200	30,100	38,700	-1,500	28,600
Center	Alba, Brasov, Covasna, Harghita, Mures, Sibiu	29,200	53,500	24,300	52,500	-1,000	23,300
Bucharest-Ilfov	Bucharest and Ilfov county	71,400	78,300	6,900	77,100	-1,200	5,700
TOTAL	ROMANIA	247,600	558,700	311,100	547,200	-11,500	299,600

THE MAIN OPTIONS OF USE

1. Disposal
a. Municipal waste landfills
- It requires advanced dehydration and is restricted by the reduced amount of organic matter admitted to storage;
- It is considered a temporary option.

b. Dedicated lands
- It requires advanced dehydration and is restricted by the reduced amount of organic matter admitted to storage;
- It is not a feasible option for a long term.

2. Other processes
a. Resource / energy recovery
- Energy recovery of the biogas resulted from the anaerobic digestion;
- Result in a product with low calorific value, suitable for disposal on land or in landfills.

b. Composting
- Ensures a sustainable use from the environmental protection point of view, economic efficiency and the quality increasing of life through the achievement of a practically, agricultural fertilizer without using restraints;
- integral collection of the sludge (non-hazardous waste category) on receptors (land disposal);
- high efficiency in relation to investment and operational costs;

- Medium and long term feasible option.

3. Use on lands

a. Agriculture

- They are used for cereals and technical plants under the conditions of meeting the quality criteria and the institutional framework;
- They are not used in fruit growing, vegetable growing, grassland, fruit trees, except for high quality compost.

b. Forestry

- Limited use for saplings, wood plantations for timber or wood for fuel.

c. Land reclamation

- Limited use to cover waste dumps, non-hazardous landfills or in reallocated industrial areas.

4. Energy recovery

a. Incineration

- Feasible solution only for large amounts of sludge;
- The sludge must meet specific conditions for use as a fuel [high calorific value (3000-3200 kcal/kg SU), humidity < 20%, etc.];
- Very high investment and operating costs.

b. Combustion in industry

- "Trouble shooting" solution especially for sludge in the category "hazardous waste";
- Problems regarding the “receiver” acceptance and external costs.

Note: The sludge management and recovery by disposal on agricultural lands implies a sequence of restrictions and compliance with specific regulations related to: compulsory passivation before use, physical-chemical characteristics for sludge-receptor, microbiological and bacteriological loading in pathogens, long-term monitoring of the environmental changes, etc.

SEWAGE SLUDGE COMPOSTING

The application of the treated bio solids in agriculture is beneficial because organic matter improves the soil structure, water retention capacity, water infiltrations and soil aeration. Also, the macronutrients (nitrogen, phosphorus, potassium) and micronutrients (Fe, Mn, Cu, Cr, Se and Zn) help plants growing. Organic matter also contributes to the soil capacity of the cations exchange which allows it to retain potassium, calcium and magnesium. The presence of organic matter improves biodiversity in the soil and helps plants in growth. The nutrients from treated biosolids can also replace the chemical fertilizers (Trasca et al., 2008).

The purpose of sewage sludge composting is to transform it through a biologically managed process into a humus-rich product that can be recovered and is suitable for many useful applications in agriculture, landscaping and private gardening.

The compost is a supplier of humified organic matter (humus and complex clay) and nutrients and serves as an organic breeder for soil and constituent in culture media and other mixtures.

Rules for composting technologies:

1. Fulfilment of legal requirements and best available technique principles (BAT) with respect to safety engineering, environmental protection, workers and neighbours’ health protection etc.;
2. Low-loss decomposition of the organic source materials into more or less mineralised/ humified organic substrates (mature or semi mature compost);
3. Optimisation of the composting system and process management in order to achieve the minimum possible emissions (odour, other volatile compounds, waste water, bio-aerosols, noise) including systems of record keeping, process control and documentation;
4. Regular compliance tests with defined quality requirements of compost products.

Composting is a self-heating (exothermic) degradation process, which depends mainly on material mixture, moisture, volume and particle size distribution, as well as the extent of agitation and aeration.

Composting must be managed in order to maintain a desired temperature range, which selects for certain communities of micro-organisms. These can be broadly classified as:

- Psychrophilic 0 to 20°C Bacteria and mould fungi;
- Mesophilic 15 to 42°C Bacteria, including a specific group called the actinomycetes and fungi;
- Thermophilic 45 to 75°C Bacteria, including the actinomycetes and other spore-forming generators.

The main composting systems available on the market today are:

1. Open windrow composting with passive aeration with variable turning frequency and size;
2. Open windrow composting with passive or forced aeration, with constant shape, aeration can be achieved both by turning the pile / rotation of the material and by insufflation by means of underfloor aeration tubes;
3. Housed windrow composting with passive or forced aeration with varying turning frequency and windrow shape;
4. Composting in a closed system, covered with semipermeable membranes and forced aeration;
5. Compost tunnel with forced aeration (the intensive composting phase is carried out inside the tunnel, controlling physical parameters (temperature, humidity, oxygen level) and the previous and subsequent phases (reception, blending, maturation, sifting, storage etc.) are similar to those from the other systems outlined above (Feodorov, 2016).

In the following it is presented a comparison between closed composting systems and open-technology composting systems (process control, leachate management, process air, odor emission control, greenhouse gases and volatile organic compounds) from an operational point of view (ease of operation, dependence on climatic conditions, necessary staff, machinery, space required) but also from the point of view of the obtained results (Table 4).

Table 4. Comparison of enclosed composting systems with the open windrow composting systems

Criterion / control parameter	Enclosed composting systems		Open windrow composting
	Tunnels, enclosed enclosures, horizontal or vertical reactors	Membrane semipermeable ePTFE systems	
Process control	Possibility to technically control composting parameters like O_2 supply, CO_2 concentration in the exhaust air, temperature, humidity. Most importantly in enclosed systems is the maintenance of sufficient water content as well as avoiding dry stabilisation at an early stage. In addition a weekly to fortnightly turning is applied in order to re-structure the piles. Water is applied mostly by sprinklers. In most facilities after hygienisation and intensive rotting, the material is extracted from the rotting box or tunnel and further composted on a hard surface with forced aeration.	Provides the possibility of monitoring process parameters such as the temperature of the treated material and the oxygen level, as well as the possibility of controlling the process by automatically controlling the blower that introduces clean air into the system. Due to the ePTFE semipermeable membrane characteristics, it is not necessary to return the material during the treatment except between the phases. It is not necessary to water the material during the process.	Process control is done via turning. Watering is preferably done by spraying during turning with water injectors installed at the turning machine Visual humidity control or by squeeze test Temperature control with calibrated manual temperature probe or with online supervision of temperature and wireless transmission to a computer based monitoring system. Optional: O_2 or CO_2 measurements by probes
Dependency on climatic conditions	In principle independent from weather conditions	Independent of climatic conditions. The system operation is proven by the operation of such installations located on all continents	Dependent upon weather conditions. Independent of precipitation in case of roofed facilities (in sheds) . Dependence on ambient temperature cannot be eliminated.
Waste water management	Leachate and surface water from storage and open maturation areas – depending on climatic conditions – can also be used for the watering during the intensive decomposition phase.	The leachate is collected separately from the rainwater through the aeration channels and can be scattered over the next lots of compost material in order to bring them to the required humidity level. The rainwater is separated from the composite and leachate by means of the semipermeable membrane and is discharged from the composting platform through separate channels for this purpose	In the case of roofed compost areas or in locations with little rainfalls (< 400 - 600 l/m²) and if the humidity is managed properly, excess water can be extensively avoided. Without roofing, contaminated leachate and surface water must be drained off and stored in a leak proof retention basin. The waste water is, to a large extent, used for watering during the composting process. Excess water can be spread on land (depending on a positive approval by the competent authority) or delivered to a waste water treatment plant.

Hygienisation	An effective thermal hygienisation at a temperature of > 55 °C can be guaranteed for the entire material if: 1) there is adequate humidity and 2) aeration (sufficient pore volume and structure stability) is provided throughout the cross section of the piled material. At least one mechanical turning is required in order to include all material compartments in the optimum microbiological decomposition conditions	Due to the efficiency of the semipermeable ePTFE membrane and the automatic process control system, temperatures often reach temperatures above 65 °C in almost any climatic condition (ambient temperature can drop to -20 °C without affecting the aerobic decomposition process). This ensures the hygiene of the entire mass of compost material	For open pile systems, at least 3 to 5 turns are required during the high temperature phase to homogenize the material. Hygiene in this case is dependent on climatic conditions, the duration of the sanitation process being much higher if the ambient temperature is low and / or rainfall occurs during composting.
Exhaust air management	Capture of waste air includes the options: 1. recirculation, 2. raw gas treatment and conditioning, 3. cooling 4. purification by a bio filter 5. stripping of excess ammonia by a wet scrubber system 6. oxygenation etc. A considerable problem of housed systems is the fact that it needs an enormous energy consumption to provide the necessary oxidative conditions in the hall atmosphere.	The semipermeable membrane ePTFE also plays a role in the biofilter. The combination of the membrane pore structure and the "wet brush" effect due to the condensation formed on the inner side of the membrane allows more than 97% of the odor and volatile organic compounds to be retained in the exhaust air. In addition, the membrane retains pathogens and bio aerosols. Due to these characteristics, in the case of positive forced aeration systems, the need for the installation of a bio filter for the exhaust air is eliminated. Such facilities can be located in the immediate nearness of inhabited areas.	Without forced aeration systems, odour emissions and possible excess GHG and ammonia emissions can be prevented by close observation and control of the parameters: 1. material composition, 2. humidity 3. cross-section and windrow size 4. turning frequency 5. the choice and consideration of the location with regard to sensitive receptors.
Decomposition rate	Shortening of the composting time and effective degradation of easily decomposable organic compounds during the controlled intensive/ high temperature rotting phase of 2 to 3 weeks (under optimised composting conditions, this can be up to 50 % degradation of the original organic dry matter in the case of typical organic household waste). This entails less demanding requirements during a second decomposition phase and maturation	For closed systems with ePTFE semi-permeable membranes, the duration of a complete compost cycle is between 6 and 8 weeks, depending only on the input material and the expected result. Generally, in order to obtain quality compost, four weeks are required in phase 1 intensive treatment (with forced aeration under the membrane), two weeks in the second phase of intensive treatment (with forced aeration under the membrane) and two weeks for maturation (aerated but without membrane)	In the case of 7 - 10 days turning processes, obtaining good results (quality compost) takes place between 16 and 36 weeks. Here, the initial mixing of the material must be done carefully and the windrow size (height) should be reduced to approximately 120 cm. Compost time can be reduced by optimizing the mix, increasing the flow rate, accurate humidity control, air and temperature management
Footprint required	This varies greatly and depends on the chosen composting system. For the decomposition and maturation period, the processed quantity ranges from 5 ÷ 9 t/m^2/ year.	Semi-permeable ePTFE membrane systems and positive forced aeration allow efficient space utilization. The piles can go up to 50x8x3,5 m (Lxwxh). The processed quantities can easily reach 6-9 t/ m^2/year m^2/t	Under optimal operating conditions it can process up to 2t/m^2/year
Necessary personnel	Reduced work places due to far-reaching automation of the process control.	Such systems are very simple to operate and do not require large or highly qualified staff. It does not require the use of rotating piles, this being done with the front loader. Installations up to 1,000,000 t / year can be operated with only a few employees.	One well trained plant operator can produce up to 5,000 t compost per year. The condition is that the facility to be equipped with devices and machines (automotive turner, high capacity loader, screening machine etc.)
Odour emissions and management	Can effectively prevent odours due to forced aeration and exhaust air recirculation. The waste air is either used to aerate piles in maturation stage (bio filter effect, supply with heat and humidity) or it is treated in a bio filter system with or without preceding wet scrubber.	Odor management is very simple and efficient. The semi-permeable ePTFE membrane helps retention up to 97% of odors. It also retains volatile organic compounds and greenhouse gases. By designing and defining the flow it prevents contamination of the compost with input material.	A well-adapted material mix, the addition of mature compost and soil, a balanced watering and oxygen supply by mechanical turning may reduce odor emissions effectively. However any escape from the process can lead to the release of strong odors in the atmosphere. Treating large quantities of raw

	A crucial prerequisite is the well designed and effective decomposition during the main, intensive composting phase. Otherwise, significant odour problems occur after extracting the raw compost from the enclosed facility.		material requires considerable effort and high fuel consumption to control the process and, implicitly, odors
Feedstocks	Enhanced flexibility of the process, capable of treating a broad range of specific feedstocks with respect to highly reactive organic matter, humidity, structure, etc.	In enclosed systems with semipermeable membrane ePTFE, any kind of organic matter can be treated: green waste, separately collected organic waste, wet fraction of solid municipal waste, sludge from sewage treatment plants, animal manure from cows, pigs, birds, etc.	Different types of organic matter can be treated with good results if the personnel are well trained to properly manage the composting process.

CONCLUSIONS

Composting sludge from sewage treatment plants represents an intensive activity and in the case of large sewage treatment plants, a large-scale activity requiring specific technologies, equipment and activities. This sludge treatment method from sewage treatment plants is an effective solution in order to significantly reduce the costs associated with disposal and also allows the production of excellent compost that can be sold for use as a natural product to improve the characteristics of soil.

It is noteworthy that, irrespective of the composting method chosen, the sludge from the treatment plants requires mixing with a material that provides the structure to the mixture (to allow air circulation), to ensure an appropriate relationship between carbon and nitrogen, to assist the bacterial activity and, last but not least, be available near the composting plant.

Current legislation in Romania does not fully address the sludge from sewage treatment plants and only refers to heavy metals content when it comes to removing them without taking into account that they contain, in most cases, dangerous pathogens for people and animals. It is necessary the intervention in the near future of the specialists in the field on the current legislation in order to correct and improve it. In old Member States, the compost from sludge treatment plants is used in several applications respectively: fertilizer in agriculture, as tailings cover, erosion protection at slopes, in forestry and as daily cover material on a municipal waste landfill because, unlike the sludge from which it comes, it is physically and chemically stable and does not release odours.

Removal of sludge from a sewage plant can be a cost-effective or even revenue-generating operation with a beneficial influence on the water treatment fee.

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