Vermicomposting of Sewage Sludge — Experiences of A Laboratory Study

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Abstract: Proper treatment of communal sewage sludge has become one of the most important issue in environmental protection. Among the possible technologies, vermicomposting could offer an environmentally sustainable solution for sludge treatment of communal sewage facilities. In the same time, integration of vermicomposting into industrial operation is challenging due to the variance of the substrate and the limits of the adaptation of the worms. In our study, vermicomposting of communal sewage sludge was carried out by comparing two redworm populations in laboratory. During a 10-week experimental period, the temperature and the redox potential were measured every other day. Other physical-chemical basic parameters were measured weekly. It can be concluded that vermicomposting of communal sewage sludge has resulted in an excellent humification process. The basic physical and chemical parameters referring to humus quality and quantity also indicate a good progress despite an initial recession. The changes of the important chemical parameters (nitrogen, phosphorus, potassium) in nutrient management were developed favorably. This paper aims to report on the research methodology and describe the results of the laboratory investigation, which is a preparatory study of a later industrial use of this technology.

Key words: Sewage sludge, vermicomposting, sludge treatment technology.

1. Introduction

The appropriate treatment of the municipal sewage sludge is one of the most important fields of today's environmental protection. Among the possible technologies, vermicomposting of municipal sewage sludge can be one of the most environmentally sustainable solution, providing valuable humus as the outcome of the process [1]-[3]. Another advantage of vermicomposting is the relative low level of investment. The further advantages of vermicomposting are reducing the number of pathogens, increasing the humus and nutrients contents, and decreasing the heavy metals content of compost [1], [4]-[9]. The most important disadvantage of the technology is that the worms utilized for vermicomposting, while can adapt to sewage sludge of different sources, require some basic conditions for living in and reproduction. In our study, we endeavored to trace the vermicomposting progress under laboratory conditions as a preparatory investigation in our project aiming to put vermicomposting in industrial use.

Redworm (*Eisenia fetida*) was involved in the experiment. This species is a well-adapted specialist to certain conditions, as an important participator in further exploration of degrading organic matter and as a resident of manure or compost. Due to their metabolic processes, the worms use the old bacterial cells from the sludge, thus newer bacterial colonization can develop contributing to the acceleration of composting processes. According to some studies [10], [11] the breakdown rate was increased in the vermicomposted sludge up to 25 times compared to the control. First large scale compounds were tested in Canada, where initially 17 tons biodegraded sludge compost was produced with vermicomposting in 1970 [12].

2. Materials and Methods

In our research the substrate was municipal sewage sludge originated from Érd (Hungary). The measured dry matter content was 15%-20%. The half part (50%) of the dry matter content was organic type. Toxic element content of the sewage sludge did not exceed the limit of the permitted toxic elements and harmful substances in sewage sludge for agricultural use according to EU standards.

Our experimental period lasted for 10 weeks. The experiments were carried out in plastic boxes, which bottoms were leaky in several points in order to prevent the development of anaerobic conditions. The surface of the box is 40 cm × 60 cm = 0.24 m^2. Two different worm populations were used in the experiments: one from Érd (marked G1) and the other from Gyöngyöstarján (marked G2). In both cases three replicates had been set with three control boxes. The study was carried out under two different environmental conditions: one was in the laboratory building (indoor conditions) and the other was in outdoor environment exposed to weather conditions. The most important meteorological data (e.g. air temperature, atmospheric pressure) were measured. The total box number was 18 in the two locations. It is important to mention that we did not cover the boxes, thus the outdoor units were exposed to environmental effects (rain, wind and indirect sunlight).

In the experiment, we did not mix the sewage sludge with any other organic materials and during the experimental period we did not manipulate the substrate in any other way.

The initial sewage sludge (state 0) was measured: dry matter content, standard MSZ-318-3:1979, organic matter content, standard MSZ-318-3:1979, pH (H_2O), standard MSZ-318-4:1979, EC (electrical conductivity), from which the total salt content could be calculated, standard MSZ-08-0206-2:1978, phosphorus content (P_2O_5), standard MSZ-318-19:1981, potassium content (K_2O), standard MSZ-318-8:1986, humus quality according to standard Hargitai [13], humus content (H%), standard MSz-08-0012-6:1987, dehydrogenase enzyme activity, standard MSZ-08-1721/3-86.

During the experimental period the every other day measured variables were: temperature (using soil thermometer) and redox potential (using ORP portable (hand-held) meter, ORP = oxidation reduction potencial). The weekly measured variables were: determination of appearance, color, smell, pH (H_2O), dry matter content, organic matter content, EC (electrical conductivity), from which the total salt content can be calculated, total nitrogen content, phosphorus content (P_2O_5), potassium content (K_2O), calcium content, manganese content, humus content (H%), humus quality according to [1] and [13], dehydrogenase enzyme activity standard MSZ-08-1721/3-86 [6].

3. Results and Discussion

The results of the initial sewage sludge (state 0) can be seen in Table 1.

Based on these measurement results, the compost process of the sewage sludge had begun. The temperature of compost boxes compared to the initial temperature had increased (Fig. 1 and 2). This was consistent with the literature [11] describing temperature increase as a typical process in the initial part of this type of experiments. According to measured redox potential values in all boxes aerobic conditions were dominant. The change of the environmental factors is shown in Table 2.

The average temperature change can be seen in the open environment experiment in Fig. 1, while the average temperature change in the closed environment is shown in Fig. 2. Based on the results in relation to the initial temperature, the ambient temperature had a significant influence. Compared to the initial temperature (18.8°C) in the open environment, the compost's average temperature was (25.2±4.1) °C, which means 34.0% increasing. Compost's temperature in indoor environment was (23.6±2.7) °C which is corresponding to 25.5% increase.

Table 1. The Basic Data of Municipal Sewage Sludge

Parameters	Measured values
Moisture content (%)	81.93
Organic matter content (%)	49.58
pH (H_2O)	6.72
total salt content (csalt) (mg/dm^3)	2165
Humus content (H%)	15.61%
Humus quality (Q):	
400 nm	0.364
480 nm	0.509
540 nm	0.365
670 nm	0.567
$CaCO_3$%	1.47
Ca (mg/kg)	6063
Mg (mg/kg)	1223
P_2O_5 (mg/kg)	2293
K_2O (mg/kg)	293.1

Table 2. The Summary Data of the Environmental Factors (the average of all experimental boxes' results, *n*=206)

Parameters	Under open environment	Under closed environment
Air temperature (°C)	26.8±4,9	23.0±2.5
Temperature of compost (°C)	25,2±4.1	23.6±2.7
Redox potential (mV)	93.72±42.38	153.81±68.13

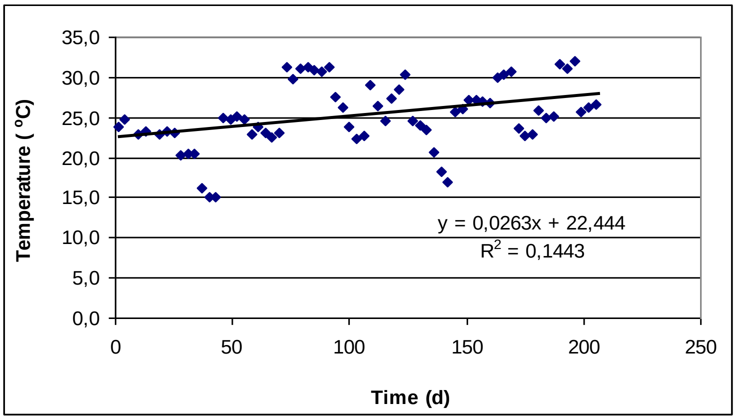

Fig. 1. Average temperature change of the compost in the open environment, depending on the number of days.

In the first ten-week of the experimental period, total of 58 samples were taken and the most important physical and chemical properties were analyzed. Furthermore the comparisons of average samples during the first ten weeks are shown compared to data of initial sewage sludge (Table 4-Table 10). In each tables, the means and standard deviations can be seen in open and indoor environment, and the worm populations' (marked G1 and G2) means and standard deviations are shown as well.

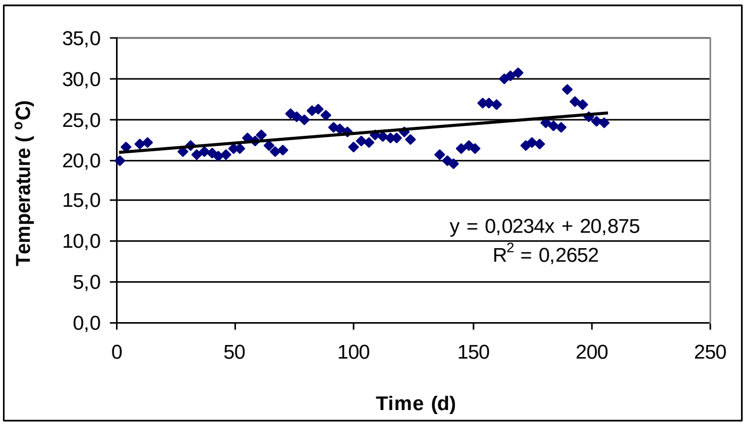

Fig. 2. Average temperature change of the compost in closed environment, depending on the number of days.

During the ten-week experimental period the average pH (H_2O) results are shown in Table 3. Based on the data, the pH increased compared to the initial state in the two different environments and in both measured worm populations. Small increase in pH refers to the aerobic digestion process, which confirms that the composting started and the aerobic processes dominate. The pH decrease (acidity) would indicate anaerobic degradation, such as in the case of blind samples were not observed. The biggest change was found in the worm population marking G2 in closed environment, which pH increased (alkalinization) compared to initial state during the ten-week experimental period.

Table 3. The Change in pH During the Measured Experimental period (n=10)

	pH					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	6.72	6.72	6.72	6.72	6.72	6.72
Mean	6.95	7.10	7.27	7.03	7.17	7.34
SD	0.21	0.19	0.28	0.19	0.22	0.28

The average conductivity results are shown in Table 4. Based on the data, the samples had significant conductivity and total salt content as well, but it can be explained by the salt content of the original sewage sludge. The conductivity values were nearly the same based on the ten-week average data, a small amount of conductivity decrease and thus a small amount of total salt content decrease were observed, which was related to the start of humification processes. The highest decrease was observed in the worm population marked G2 under open environment (21.85% decrease compared to initial state). The average total salt content results are shown in Table 5. The highest decrease was found in the worm population marked G2 in open environment based on the ten-week average values compared to the initial state (24.11% decrease).

Table 4. The Change of Average Conductivity during the Measured Experimental Period (n=10)

	EC (mS/cm)					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	4.33	4.33	4.33	4.33	4.33	4.33
Mean	4.28	3.99	3.42	3.73	6.00	4.72
SD	0.69	0.46	0.29	0.50	0.99	0.83

The change of the mean of phosphorus content is given in Table 6. Based on the average values of the ten-week experimental period, a small amount of change in phosphorus content could be observed. The highest decrease was found in the blind samples in closed environment (9.61% decrease), in all other cases the decrease did not reach 9.00%. In spite of the decrease, the phosphorus content of the compost samples is still good for agricultural use. Compared to the generally accepted value, which is 150-160 mg/kg for most of the cultivated crop and the soil type, the measured phosphorus concentrations are higher with an order of magnitude in both worm populations and under both environmental conditions.

Table 5. The Change of Average Total Salt Content during the Measured Experimental Period (n=10)

	c (salt)(mg/dm^3)					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	11150	11150	11150	11150	11150	11150
Mean	10751.50	10008.00	8596.78	9333.50	14945.00	11829.44
SD	1656.32	1210.26	754.41	1214.68	2467.73	2050.10

Table 6. The Change of Average Phosphorus Content during the Measured Experimental Period (n=10)

	P_2O_5 mg/kg					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	2293.3	2293.3	2293.3	2293.3	2293.3	2293.3
Mean	2051.29	1890.45	1897.29	1872.97	1916.09	1875.90
SD	627.73	449.88	444.71	360.94	385.27	372.31

The results of average potassium content are shown in Table 7. During the ten-week experimental period under both environmental conditions and in both worm populations the change was significant, more than an order of magnitude increase was observed. The highest increase are almost the same in open environment between worm populations G1 (506.33%) and G2 (507.85%). Compared to the generally recommended value, which is 180-200 mg/kg independently of the cultivated crop and the soil type, the potassium content is higher, which is an advantage for agricultural use.

Table 7. The Change of Average Potassium Content during the Measured Experimental Period (n=10)

	K_2O mg/kg					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	293.1	293.1	293.1	293.1	293.1	293.1
Mean	1462.67	1674.53	1665.60	1601.68	1486.26	1541.21
SD	628.67	477.89	557.22	548.65	612.61	622.21

The change of average moisture content of the compost samples are shown in Table 8. Based on the data, apart from one experimental setting (closed conditions, worm population G2), small amount of decrease was observed in all cases. The ten-week average moisture results correspond to the living conditions of worm populations. The highest decrease (25.26%) was found in open environment in the blind samples. The measured results were confirmed by the on-site visual check. It can be observed that the top layer of the blank samples dried out just a few centimeters and the first signs of clot formation appeared. Visible moisture content decrease was found in open environment with worm population G2 too.

The change of average total organic matter content (ignition loss) is shown in Table 9. Based on data, the total organic matter content was increased except two cases: in the blind sample in indoor environment and in the G2 population in open environment. In the case of the G2 outdoor sample the significant temperature changes caused worsening of living conditions for the worms, to which the G2 population could not adapt as effectively as the G1.

Table 8. The Change of Average Moisture Content during the Measured Experimental Period (*n*=10)

	Moisture content (%)					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	81.93	81.93	81.93	81.93	81.93	81.93
Mean	50.19	74.37	72.34	69.72	74.93	82.70
SD	19.49	4.39	8.39	13.21	12.07	7.34

Table 9. The Change of Organic Matter Content during the Measured Experimental Period (*n*=10)

	Ignition loss (organic matter content) (%)					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	49.58	49.58	49.58	49.58	49.58	49.58
Mean	52.85	53.27	49.42	44.82	54.77	57.48
SD	2.71	2.79	4.99	8.46	1.13	1.55

The change of humus content is summarized in Table 10, which shows that the values measured in the ten weeks increased significantly compared to the humus content of initial sewage sludge under both environmental conditions and in both worm populations. The biggest increase was found in worm populations marked G2 in an open environment.

Table 10. The Change of Average Humus Content during the Measured Experimental Period (*n*=10)

	Ignition loss (organic matter content) (%)					
	Open environment			Closed environment		
	Blind	G1	G2	Blind	G1	G2
Initial state	49.58	49.58	49.58	49.58	49.58	49.58
Mean	50.35	51.67	52.04	40.08	54.23	56.68
SD	4.91	3.20	5.68	9.59	2.11	3.28

It can be observed in Fig. 3 and 4, that the humus content increased compared to the humus content of initial sewage sludge under both environmental conditions and in both worm populations (apart from one case). The volatility of the humus content change in outdoor samples reflects the changing meteorological conditions. Decreasing humus content in the G2 population under outdoor conditions is accompanied by the decrease in the quantity of living worms. More static laboratory experiments clearly indicate the turn, from which the decline in humus content starts.

The change of humus quality in the compost boxes was continually measured. The change of the humus stability number (Q) of the initial sewage sludge is shown in four different wavelengths (400, 480, 540 and 670 nm). Data of the outdoor units can be found in Table 11, while Table 12 shows the results of the indoor boxes. It can be concluded, that the humus stability number has been increased compared to the initial state under both environmental conditions and in both worm populations during the ten-week experimental period, which is characterized by the valuable high molecular weight humus quantity's increase.

Under laboratory conditions, we were able to mark a turning point clearly, from which the humus content of the substrate started to fall. In the same time, we had observed that both of the two different redworm populations were able to adapt to municipal waste water sludge. In the same time, the G1 population had generally shown better performance in the humification process.

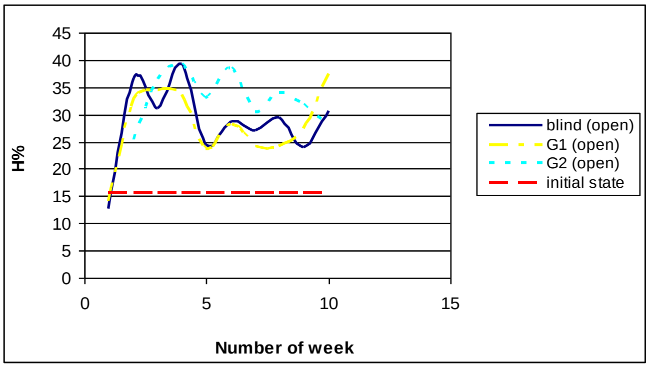

Fig. 3. The change of humus content in an open environment.

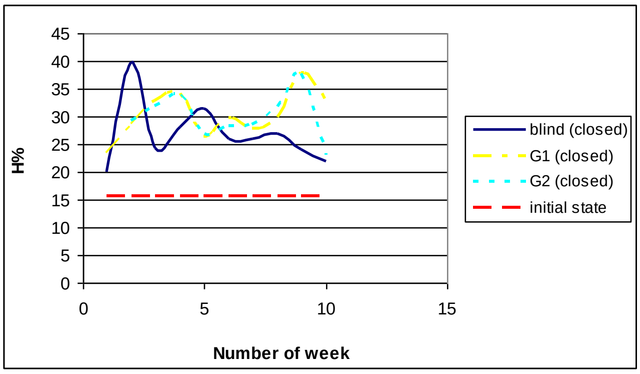

Fig. 4. The change of humus content in a closed environment.

Table 11. The Change of Humus Quality in an Open Environment during Measured Experimental Period (n=10)

	blind			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	0.638	1.066	1.283	1.688
SD	0.273	0.386	0.688	0.723
	G1			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	0.829	1.110	1.453	3.393
SD	0.354	0.508	0.804	3.323
	G2			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	0.689	0.948	1.104	1.740
SD	0.220	0.294	0.332	0.644

We are going to continue the series of laboratory experiments under both environmental conditions and with both worm populations to be able to get more data for further analysis. In the same time, a bigger scale experiment with a total of 6 extensive sites with a total of 29 m^3 of municipal sewage sludge has also been started based on the laboratory experiences.

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Table 12. The Change of Humus Quality in A Closed Environment during Measured Experimental Period (*n*=10)

	blind			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	0.899	1.369	1.482	2.094
SD	0.505	0.957	0.995	1.728
	G1			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	1.493	1.470	1.592	2.503
SD	0.892	0.771	0.670	1.976
	G2			
	400 nm	480 nm	540 nm	670 nm
Initial state	0.364	0.509	0.364	0.566
Mean	1.144	1.364	1.725	2.672
SD	0.666	0.534	1.044	2.035

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Barbara Bódi was born in Nyíregyháza in 1987. She graduated as a food safety engineer from the Faculty of Food Science, Corvinus University of Budapest, Hungary in 2012. Currently, she is a PhD student working on waste management solutions in order to minimize the environmental impact of household food waste in Hungary. During her studies she acquired practical knowledge in the field of classical and instrumental analytical methods and quality assurance. In the framework of PhD program she could participate in several quantitative researches and had possibility to acquire experience in using statistical methods.

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Levente Kardos was born in Budapest in 1979. He is a chemistry and environmental science teacher in the Faculty of Natural Sciences, Eötvös Loránd University, a environmental engineer in Budapest University of Technology and Economics, and environmental chemistry PhD in the Faculty of Natural Sciences, Eötvös Loránd University. He is a senior lecturer, and the deputy head of the Department of Soil Science and Water Management. The main research topic is the sewage sludge utilization, primarily anaerobic digestion and composting of sewage sludge.