THE PILOT-SCALE VERMICOMPOSTING OF DEWATERED SEWAGE SLUDGE FROM A MEDIUM-SIZED WWTP

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INTRODUCTION

- Sewage sludge contains nutrients and other substances that are able to positively contribute to the enhancement of the properties of soil and overall fertility (Latare et al., 2014). Its reuse, where suitable, is encouraged by Council Directive 91/271/EEC. Treated sludge in the Czech Republic must fulfil the quality criteria set for toxic metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn), AOX, PCB and PAH and the microbial pathogens *Salmonella* sp. and *Escherichia coli* (Ministry of the Environment of the Czech Republic, 2021). Apart from those pollutants whose concentrations are regulated, a broad spectrum of so-called 'emerging' organic chemicals, including pharmaceuticals and other personal care products (PPCPs), may be transferred to residual solids during the treatment of wastewater. Thus, a reliable assessment is required of their significance and implications for the beneficial recycling of treated sewage sludge.
- Vermicomposting is a process via which earthworms act to convert organic materials (usually waste) into a humus-like material known as vermicompost. It comprises a bio-oxidative and stabilizing process for the conversion of organic material which, unlike classical composting, uses the interaction between the intensive activity of earthworms and microorganisms, and does not involve the thermophilic decomposition phase. (Dominguez and Edwards, 2011; Champar Ngam et al., 2010). Vermicompost generally appears to be superior to conventionally-produced compost in terms of a number of important parameters.
- Our study concerns the long-term field testing of sludge vermicomposting in two separate pits, each with a working volume of 3m^3. Straw was used as the bulking material in two mixing ratios. The research covered the testing phase of a pilot vermi-composter conducted for the purpose of follow-up experiments focusing on the reprocessing and sanitation of sewage sludge. The aim was to ensure a sufficient inoculum density and to test the overwintering of the system under outdoor conditions. However, even during this start-up phase, all the parameters required to be monitored by Czech legislation, as well as the contents of macro- and micro-nutrients such as N, P, K, Mo, Ca and Mg were monitored, as was the development of the concentration of selected PPCP micropollutants.

MATERIALS AND THE DESIGN OF THE FIELD EXPERIMENT

- The dewatered sewage sludge was taken from WWTPs of a 33 thousand population-size equivalent (p.e.) located in South Bohemia. The straw was supplied by a local farmer. The earthworms (*Eisenia andrei*) were supplied by the FLORIUM s.r.o. vermicomposting plant.
- The pilot-scale vermicomposting experiment is being conducted in segments A and B of a field vermi-composter (see images 1, 2 and 3). The working volume of each segment (A and B) is 3 m^3. The working volume of the backup segment (C) is 3.5 m^3; this part of the vermi-composter serves as the earthworm inoculum for subsequent experiments. The drainage system of the field vermi-composter allows for the leachate sampling of each segment. The excess leachate is collected in an underground tank with a volume of 1 m^3 and subsequently disposed of at the nearest WWTP. This experiment does not include the monitoring of the leachate.

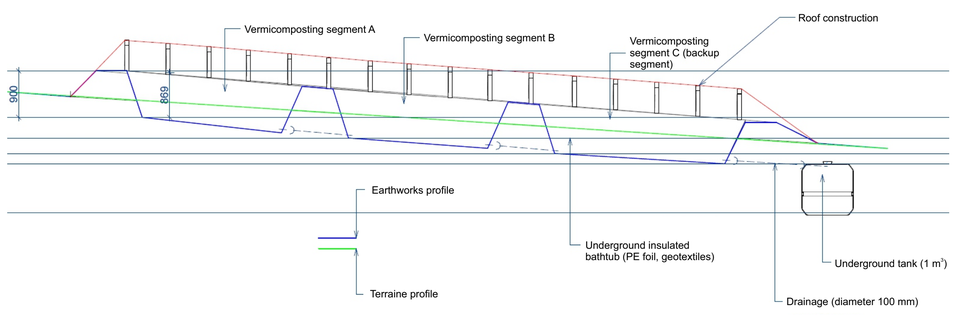

Figure 1: Scheme of the pilot-scale vermi-composter

- A perforated drainage pipe made of PVC was positioned at the bottom of each segment and covered with a layer of straw (36 kg for each of the segments A and B). After separating this drainage layer with a geotextile material, each of the segments was filled with the test material according to the following arrangements:

Segment A : 4 layers of straw (40 kg in total) and 3 layers of dewatered sewage sludge (608 kg in total, representing 159 kg of dry matter). Straw formed the bottom and upper layers. The weight ratio of the straw to the dry sludge was 1:4.

Segment B: 3 layers of straw (30 kg in total) and 2 layers of dewatered sewage sludge (the same amounts as in segment A). Straw formed the bottom and upper layers. The weight ratio of the straw to the dry sludge was 1:5.3.

- After filling the vermi-composter with a substrate, two perforated PP boxes containing the earthworm hybrid *Eisenia andrei* were placed in each segment. The total weight of the earthworm inoculum was 7 kg for each segment.
- The vermicomposting process commenced on 4 June 2020 and is ongoing. Both segments were sprinkled twice with the same amount of water during the dry summer of 2020. Otherwise, a perforated cover was sufficient to provide the necessary irrigation.
- In November 2020, compact piles were formed from the vermicompost layers of the two segments, in the lower one-third of the segment in both cases. This arrangement allowed the earthworms to overwinter comfortably via the creation of non-freezing zones. In addition, this form of vermicompost will serve as the inoculum for the next batch of sludge in the so-called wedge system (currently in progress).

SAMPLE ANALYSIS

- *E. coli* was determined according to the Czech national standard ČSN EN ISO 9308-1. The *Salmonella* sp. was determined according to ČSN EN ISO 6579.
- The determination of heavy metals, the Ca, Mg, K, P and N contents, the pH, the DMC, conductivity and the content of TOC, PCBs (the sum of 7 congeners -28+52+101+118+138+153+180), PAHs (the sum of antracene, benzo(a) antracene, benzo(b) fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, fenantrene, fluoranthene, chrysene, indeno(1,2,3-cd)pyrene, naftalene and pyrene) and AOX was conducted by an accredited analytical laboratory.
- Samples intended for the PPCP and endocrine disruptor analysis by means of LC-MS/MS were freeze-dried and homogenized. Each sample (weights of 1-2 g) was then transferred to an extraction cell and positioned in an Accelerated solvent extractor (ASE, Dionex). The extracts were analyzed using the LC system (Agilent 1260 Infinity) coupled with a triple quadrupole mass detector (Agilent 6470 LC/TQ). The mass spectrometric parameters were optimized using MassHunter Workstation Optimizer and Source Optimizer (both Version 10.0, SR1, Agilent).

RESULTS

- The dry matter contents of segments A and B after 1 year of processing were 28.6 ± 0.4% and 26.8 ± 0.9%, respectively. The small (but statistically significant difference, p <0.01) led to a differing worm inoculum density. Both the size and abundance of the earthworms were significantly higher in segment B.
- The concentrations of the monitored pharmaceuticals ranged from 0.5 ppb (Sulfamethazine) to 421.1 ppb (Citalopram). The total sum of 2 124.5 ± 352.7 ppb dropped in segments A and B to 1 381.9 ± 145.9 ppb and 1 340.9 ± 252.2 ppb, respectively. The observed degradation efficiencies of the various substances after 9 months are illustrated in Figure 2.

Table 1: Concentration of hazardous substances in segments A and B at the commencement and after 9 months of the process (mean and standard deviation of 3 values)

Hazardous substances (mg/kg)	A and B - input	A - output	B- output	Czech legislation limit
As	8 ± 0.16	5.2 ± 1.1	6.05 ± 0.6	30
Cd	1.3 ± 0.03	1.2 ± 0.1	1.2 ± 0.1	5
Cr	42.8 ± 4.2	42.7 ± 8.2	40.9 ± 0.7	200
Cu	248.7 ± 10.6	200.7 ± 20.6	202.3 ± 15.8	500
Hg	1.7 ± 0.5	1.3 ±0.4	1.2 ±0.1	4
Ni	29.5 ± 1.9	28.5 ± 2.8	31.1 ± 5.4	100
Pb	37.6 ± 2.6	34.6 ± 4.55	34.4 ± 2.8	200
Zn	803.7 ± 45.3	754.3 ± 80	714.3 ± 98.3	2500
Mo	6 ± 0.65	5 ± 0.65	4.7 ± 0.6	
AOX	95.7 ± 56.8	n.d.	n.d.	500
PCB (sum of 7 congeners)	n.d.	n.d.	n.d.	0.6
PAHs (sum of 12 subst.)	2.8 ± 1.1	3.5 ± 0.4	6.8 ± 1.4	10

n.d. Not Detected

Table 2: Development of selected agronomic parameters over 9 months

Parameter		A and B - input	A - output	B - output
Ca	mg/kg	23 783.3 ± 387.6	22 643.3 ± 1 687.1	19 530 ± 4 650.3
Mg	mg/kg	4 970 ± 193.1	5 020 ± 373.6	4 776.7 ± 712.9
K	mg/kg	2 710 ± 437.1	4 506.7 ± 342.7	3 883.3 ± 176.7
P_{total}	mg/kg	26 050 ± 526	39 300 ± 4 129.1	39 426.7 ± 4 696.2
N_{total}	mg/kg	8 170 ± 2 513.9	3 710 ± 816.6	3 880 ± 312.5
N_{NH4+}	mg/kg	9 216.7 ± 12 456.6	185 ± 21.2	647 ± 141.1
N_{NO3-}	mg/kg	0.8 ± 0.1	875 ± 86.2	616.7 ± 74.5
TOC	mg/kg	308 533.3 ± 44 265.1	227 293.3 ± 13 762.4	234 833.3 ± 10 072.4
Conductivity	mS/m	74.7 ± 6.4	94.9 ± 11.8	80.67 ± 9.9
pH		7.6 ± 0.1	5.2 ± 0.3	5.4 ± 0,05

Table 3: Sanitation effect of vermicomposting in segments A and B

Parallel number	***E. coli*** concentration (CFU/g)					
	Input	A	B	A	B	Czech legislation limit
	3.6.2020	**22.10.2020**		**18.5.2021**		
1	7.8 x 10^4	3.1 x 10^4	2 x 10^4	0	0	max. 1 x 10^3
2	9.2 x 10^4	3.5 x 10^4	2.5 x 10^4	0	0	max. 1 x 10^3
3	1 x 10^5	3.5 x 10^4	2.9 x 10^4	0	0	max. 1 x 10^3
4	2.2 x 10^5	3.6 x 10^4	3.4 x 10^4	0	4 x 10^2	max. 1 x 10^3
5	2.8 x 10^5	4.2 x 10^4	3.5 x 10^4	0	2.4 x 10^3	max. 5 x 10^3
	Salmonella					
1-5	negative	negative	negative	negative	negative	Negative in 5 parallel samples

Table 4: The degradation efficiency of the 5 detected endocrine disruptors (ED) after 9 months (mean and standard deviations of 6 values)

	Input ED conc.	Output ED conc. – A	Output ED conc. – B
	(ppb)	(ppb)	(ppb)
Bisphenol A	615.5 ± 63.4	93.4 ± 24.6**	158.5 ± 24.6**
Bisphenol F	29.6 ± 4.3	21.5 ± 8.4**	17.8 ± 2.2**
Bisphenol S	27.3 ± 2.6	95 ± 31.5**	45.6 ± 29.1
Estrone	3.5 ± 2.7	0.4 ± 1*	0.9 ± 1.3
17beta-Estradiol	24.8 ± 20	n.d.*	n.d.*

n.d.: Not Detected
* *significant decrease/increase (p?0.05)*
** *significant decrease/increase (p?0.01)*

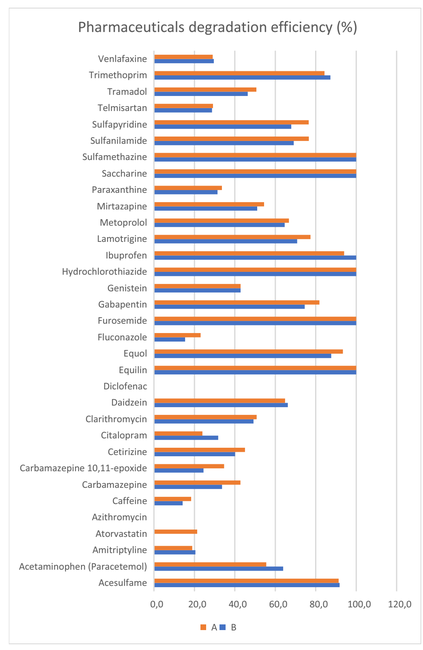

Figure 2: Degradation efficiency of selected PPCPs

SUMMARY

- During the first year of operation of the field vermi-composter, the earthworm inoculum in the mixture of sewage sludge and straw was observed to have sufficiently expanded, and the culture overwintered successfully even though frosts reached temperatures of below -20°C in the winter of 2020/2021.
- The differing sludge/straw mixing ratios exerted an effect on the output of the content of dry matter, which led to a significant difference in the size of the earthworm populations; however, no other significant differences were observed between segments A and B with respect to the various monitored parameters.
- The sludge used in the experiment met legislative requirements for application on agricultural land in terms of the contents of heavy metals and the monitored organic substances as early as at the commencement of the project. The microbiological indicators (such as the content of *E. coli* and *Salmonella*) met the required criteria in the 9th month; the influence of the winter season is being subjected to further study.
- The resulting vermicompost presents an important source of Ca, Mg, K, P and N. During the process, the N forms shifted significantly from the ammoniacal to the nitrate forms.
- The degradation potential of the selected micropollutants from the PPCPs group differed. A 35% degradation in the monitored substances was observed for segment A and 37% for segment B.
- Vermicomposting led to a significant decrease in the concentration of the 4 detected endocrine disruptors. Conversely, an increase was observed in the Bisphenol S, which was probably due to the cover material used for the insulation of the vermi-composter.
- Vermicomposting appears to be a useful method for the processing of sewage sludge, at least from smaller WWTPs. The potential of this process merits further investigation.

ACKNOWLEDGEMENT

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References:

Domínguez, J., Edwards, C., A. (2011): Relationships between composting and vermicomposting. In: Vermiculture Technology (Eds Edwards C.A., Arancon N.Q., Sherman R.), Boca Raton: CRC Press, Taylor & Francis Group, 11-25.
Champar-Ngam, N., Iwai , C.B., Ta-oun, M. (2010): Vermicompost: tool for agro-industrial waste management and sustainable agriculture. International Journal of Environmental and Rural Development, 1-2, 38-43.
Latare, A.M., Kumar, O., Singh, S.K., Gupta, A. (2014): Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice-wheat system, Ecological Engineering, 69, 17-24
Ministry of the Environment of the Czech Republic (2021): Vyhláška č. 273/2021 Sb., o podrobnostech nakládání s odpady. In: Prague: Ministry of the Environment of the Czech Republic, volume 2021, number 273.