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Effect of barley straw and coniferous bark on humification process during sewage sludge composting

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ABSTRACT

This study investigated how different amendments (barley straw, coniferous bark) influence organic matter (OM) removal kinetics and humification during sewage sludge composting. With bark, high temperatures, intensive OM degradation and humification were achieved later than with straw. The rate of OM degradation was lower with bark than with straw (15.18 g/kg OM·d vs 24.07 g/kg OM·d) and the time needed for intensive HS formation was longer with bark (140 days vs 60 days). The kinetic constants for humic substances (HS) and humic acids (HA) formation were lower with bark than with straw (k_{HS} 0.025 d^{-1} vs 0.047 d^{-1}, k_{HA} 0.022 d^{-1} vs 0.044 d^{-1}). With bark, however, the increase in HS concentration during composting ($C_{max,HS}$) was higher (178 mg C/g OM vs 84 mg C/g OM), and the fulvic fraction predominated in HS (80%), whereas with straw, humic acids predominated (82% of HS).

1. Introduction

Sewage sludge is a by-product generated during wastewater treatment. Due to its high content of organic matter (OM) and plant nutrients (nitrogen, phosphorus, etc.), sewage sludge can be considered a soil modifier or fertilizer. However, the presence of unstable organic compounds and human pathogens may cause problems with its direct disposal or further use (Singh and Agrawal, 2008). Therefore, in order to acquire a stable and profitable amendment for soil, sewage sludge should be processed prior to utilization and application.

Among the different methods of sewage sludge treatment, composting is one of the environmentally preferred ones. During this process, the mass and moisture of sewage sludge decrease. Moreover, composting decomposes biodegradable organic matter and, due to the heat generated, destroys pathogens.

Sewage sludge has high water content, relatively low air permeability and a low carbon-to-nitrogen (C/N) ratio, so for effective composting, it needs to be mixed with lignocellulosic components like wood chips, bark, straw, sawdust, grass or leaves, which serve as amendments and/or bulking agents. These ingredients are used to adjust moisture content and porosity and to ensure an optimal C/N (Sánchez-Monedero et al., 2001; Zbytniewski and Buszewski, 2005; Kulikowska and Klimiuk, 2011; Kulikowska, 2016; Meng et al., 2018). A crucial indicator of the progress of composting is the degradation of organic matter (OM). The literature indicates that the rate of OM degradation depends on the type of waste composted, and that it can range from 0.196 d^{-1} for sewage sludge with lignocellulosic materials (Kulikowska, 2016) to 0.12–0.17 d^{-1} for municipal wastes (Hamoda et al., 1998), and even to 0.0048–0.0085 d^{-1} for distillery waste with animal manures (Bustamante et al., 2008). Information about degradation kinetics is important for process design, especially when estimating the time for feedstock retention during active composting in reactors or windrows.

Compost quality is also related to the concentration of humic substances (HS) in the final product; thus, determining humification progress is essential for evaluating composting process. To date, the evaluation of humification has been based mainly on the determination of the concentrations of HS and their fractions (humic acids, HA; fulvic acids, FA) (Jouraiphy et al., 2005; Zbytniewski and Buszewski, 2005; Zhou et al., 2014). It is known that humic substances comprise not only HA and FA, but also humin. However, humin cannot be extracted directly by dilute alkali or acid and the lack of research on humin materials can be attributed to their insolubility in solvent systems from which the solute is recoverable without compositional or structural alterations (Hayes et al., 2017 after Rice, 2001).

Many authors characterize HA and FA by elemental composition, mainly in terms of percentage of carbon, oxygen, hydrogen, nitrogen and sulfur (Jindo et al., 2016; Li et al., 2017). This is generally used to reveal variations in the elemental composition of HA and FA from compost at different stage of treatment

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(Amir et al., 2005, 2008; Droussi et al., 2009). Moreover, FTIR spectra of HA from compost with that of HA in soils is compared (Droussi et al., 2009). This is important, as it provides useful information on the type of exogenic organic compounds being introduced into the soil with compost.

Additionally, to evaluate humification during composting, indicators like the humification ratio (HR), humification index (HI), percentage of humic acids (P_{HA}) and degree of polymerization (DP) are calculated (Paredes et al., 2000; Jouraiphy et al., 2005; Kulikowska and Klimiuk, 2011; Zhao et al., 2016). Progress in humification may also be evaluated on the basis of changes in functional groups in HS. For example, Zhou et al. (2014) demonstrated the decrease of aliphatic and carboxylic groups and the increase of aromatic groups in HS can serve as an indicator of the stability and maturity of the compost.

Although the detailed characteristics of HS in mature compost are commonly determined, there is limited information about the kinetics of the humification progress, including the rate of formation of HS, HA and FA. Knowledge of humification kinetics allows determination of the time when the humification process has the highest intensity.

It is known that the selection of appropriate bulking agents/amendments plays an essential role in the rate and efficiency of OM degradation. However, the type of amendment may influence humification progress, i.e. the humification rate (understood as the rate of HS and HA formation), the concentration of HS, and the share of HA and FA in HS, although systematic data in this area are rather scarce. The aim of this study was to determine the effect of two amendments (barley straw and coniferous bark) on the kinetics of organic matter mineralization and humification during sewage sludge composting at pilot-plant scale. In particular, it was established how the HS concentration and the share of HA in HS in the compost, as well as the kinetic constants of humification, change when different amendments are used.

2. Materials and methods

2.1. Bioreactor for composting

The bioreactor consisted of a truncated windrow with a trapezoidal cross-section. The dimensions of the lower and the upper base of the reactor were 440 mm × 1060 mm and 850 mm × 1060 mm, respectively. The height of the bioreactor was 1530 mm. The bioreactor was aerated by air supplied from a ventilator to the perforated floor on the bottom of the bioreactor. The intensity of aeration was monitored and maintained in the range of 1–1.5 l/kg ·min in order to prevent compost overheating. The bioreactor was equipped with PT100 temperature sensors connected to LED displays, which allowed the temperature to be determined. The sensors were situated at depths of 7 and 63 cm in the bioreactor.

2.2. Characterization of sewage sludge and feedstock preparation

Two series were performed, which differed in the kind of lignocellulosic materials added as amendments/bulking agents. In both series the share of dewatered municipal sewage sludge was 65% (w/w). In series 1, wood chips were used as a bulking agent (15% w/w) and barley straw (stalks with a length of ca. 5–10 cm) as an amendment (20% w/w); in series 2, bark (pieces with a size of ca. 3–4 cm × 5–8 cm) was used instead of barley straw (25% w/w), and the share of wood chips was 10% (w/w). The sewage sludge was free of *Salmonella* spp. and eggs of *Ascarsis, Trichuris* or *Toxocara* spp.

Table 1 shows the characteristics of the sewage sludge and lignocellulosic materials. Sewage sludge had the highest content of moisture and nitrogen. Thus, the addition of lignocellulosic material improved the C/N ratio, lowered moisture content and improved the structure of the feedstock.

2.3. Analytical methods

Samples from the top of reactor were collected directly after opening the reactor cover; samples from the middle and bottom of the reactor were taken through sampling ports. Samples were gathered in accordance with the Polish regulation PN-Z-15011-1. First, 3 samples, with a weight of approximately 1 kg each, were collected from the top, middle and bottom of the bioreactor, then stacked on a paved area, and thoroughly mixed in order to prepare a representative sample for further analysis. Afterwards, the sample was shaped in the form of a truncated pyramid with a square base and a height of less than 30 cm, and then divided into 4 parts by diagonals. Next, two parts situated opposite to each other were discarded, whereas the other two were mixed thoroughly. The whole process was repeated several times to create a representative sample with a final mass of 0.5 kg. The samples were mixed and dried at 105 °C to determine their dry mass, and then ground to a diameter of 0.5 mm with a Retsch SM 100 mill. OM content was determined by ignition at 550 °C (PN-Z-15011-3:2001), and total N content, by the Kjeldahl method (PN-Z-15011-3:2001).

The dewatered sewage sludge was examined for the presence of *Salmonella* spp., and eggs of *Ascarsis, Trichuris* and *Toxocara* spp. in accordance with Polish standard PN-EN ISO/IEC 17025:2005 in a dedicated Microbiology and Parasitology Laboratory.

2.3.1. Humic substances (HS) extraction

First, samples of compost were washed three times with distilled water in order to remove soluble substances, mostly sugars and proteins. For this purpose, 50 ml of water were added to 2.5 g of compost and then the mixture was shaken and centrifuged. Second, to remove bitumen and waxes, a 2:1 mixture of chloroform and methanol was added to the sample. The extractions were carried out in a MarsXpress microwave oven at 60 °C for 10 min. The extraction process was repeated until a colorless supernatant was obtained, after that the defatted samples were evaporated to eliminate the solvent.

To obtain HS, a two-stage extraction process was performed, which allows two kinds of humic acids to be extracted, i.e. labile humic acids (L-HA) (extraction with 0.1 M $Na_4P_2O_7$ at pH 7) and stable humic acids (S-HA) (extraction with 0.1 M NaOH at pH 12, after separation of L-HA). After extraction, the content of TOC in

Table 1
Characteristic of the components used for composting and composting feedstocks.

Characteristic	Components and composting feedstocks					
	Sewage sludge	Wood chips	Barley straw	Coniferous bark	Series 1	Series 2
Moisture (%)	83.0 ± 2.7	32.0 ± 1.8	16.0 ± 0.7	44 ± 1.8	67.0 ± 1.2	71.0 ± 0.9
Organic matter (% d.m.)	76.2 ± 1.6	96.2 ± 2.1	98.1 ± 1.2	94.3 ± 1.4	70.9 ± 1.7	69.8 ± 1.9
TOC (% d.m.)	37.6 ± 1.7	47.1 ± 1.2	52.2 ± 2.3	54.5 ± 0.9	–	–
N (% d.m.)	6.3 ± 0.5	0.82 ± 0.04	1.01 ± 0.02	0.6 ± 0.04	1.82 ± 0.08	-2.03 ± 0.1