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# Organic matter transformations and kinetics during sewage sludge composting in a two-stage system

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ABSTRACT

The use of different proportions of rape straw and grass as amendments in the composting of dewatered sewage sludge from a municipal wastewater treatment plant was tested in a two-stage system (first stage, an aerated bioreactor and second stage, a periodically turned windrow). The composition of feedstock affected the temperature and organic matter degradation in the bioreactor and the formation of humic substances, especially humic acids (HA), during compost maturation in the windrow. The total HA content (the sum of labile and stable HA) increased according to first-order kinetics, whereas labile HA content was constant and did not exceed 12% of total HA. $\Delta\log K$ of 1.0–1.1 indicated that HA was of R-type, indicating a low degree of humification. Temperature during composting was the main factor affecting polymerization of fulvic acids to HA and confirmed the value of the degree of polymerization, which increased only when thermophilic conditions were obtained.



## 1. Introduction

Recycling has become an attractive solution for sewage sludge management, and yields a product potentially useful for agriculture. Composting provides a simple and cost-effective alternative treatment method for sewage sludge by decomposing organic matter (OM), producing a stabilized residue and disinfecting of pathogens. The final product, compost, is rich in humic substances (HS) and usable as an amendment in agriculture or for soil reclamation. However, low porosity, high humidity and low carbon (C):nitrogen (N) ratios in sewage sludge make it necessary to mix it with other by-products (or waste), generally C-rich lignocellulosic waste such as grass or leaves. Recently, there has been increasing interest in rape straw, mainly due to increased use of rape crops for biofuel production. Rape straw is now a widely available waste product that can be used as an amendment in composting; however, there are few studies on the impact of rape straw on composting.

Composting begins from mineralization of readily biodegradable compounds, with the process range and rate depending on the type of composted waste and operational conditions, and organic matter removal can vary from several percent (Hernández et al., 2006) to >30% (Gea et al., 2005; Hu et al., 2007). During composting, the degradation of more complex proteins, hemicellulose, cellulose and lignin leads to the formation of carbohydrates, amino acids, simple peptides and phenols of low structural complexity, which can be either degraded by microorganisms as a source of C and energy or serve as building blocks for humus formation. As the quality of compost is related to HS, the humification progress is intensively studied by monitoring changes in the C content of HS, fulvic acids (FA) and humic acids (HA) during composting. Studies have shown that during composting there is lowering of FA and increasing of HA contents (Jouraiphy et al., 2005; Paredes et al., 2002). Available literature data mainly concerns composting process in windrows, and there is little information available on C degradation and humification progress during composting of sewage sludge in two-stage systems. In this context, there is a need for composting research in a two-stage system: the first stage an aerated bioreactor, and the second a periodically turned windrow. Data on the rate of OM loss are extremely important for process design, mainly estimation of retention time of feedstock in the bioreactor that allows a balance between mineralization and humification degree.

HAs are a mixture of different molecules, with the degree of humification expressed as $\Delta\log K$. Kumada (1987) used $\Delta\log K$ (where $\Delta\log K$ is the logarithm of the ratio of the absorbance of humic acid at 400 nm to that at 600 nm) to distinguish three basic types of HA: A-type ($\Delta\log K < 0.6$), B-type ($\geqslant 0.6$ to $<0.8$) and R-type (0.8–1.1); with lower $\Delta\log K$ value indicating greater humification degree. The usefulness of this indicator follows from the fact that chemical characteristics of HA vary according to degree of humification. The literature provides information on investigations concerning humification degree of HA mainly conducted in soils. Shindo et al. (2006) demonstrated that for HA the $\Delta\log K$ increased from 0.68 for soils fertilized only with N, phosphorus and potassium

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to 0.8 for soils fertilized with nutrients plus compost. However, Rivero et al. (2004) found that compost incorporation in soil did not significantly change the HA type during a three-year study. So, estimates of $\Delta\log K$ in HA from compost may allow evaluation of maturity degree of acids introduced to soil.

In soil, parts of HA are labile and some are stable (L-HA and S-HA, respectively). According to Schnitzer and Schuppli (1989) L-HA are more aromatic than are S-HA. Similarly, Gieguzynska et al. (2009) showed that L-HAs were weakly bound macromolecules of small or medium size with an aromatic character, while S-HA were larger macromolecules of aliphatic character. Because HS are one of the most important constituents in soils and greatly affect various soil properties, determination of contribution of their different forms, i.e. potentially labile compounds (FA and L-HA), in the final compost provides useful information on the type of exogenic organic compounds being introduced into the soil with compost.

The first aim of the study was a comprehensive analysis of humification progress during sewage sludge composting in a two-stage system, using different feedstock compositions. The second – estimate the degree of HA maturity and proportions of L-HA and S-HA. The analysis of the humification process was based on HS, HA and FA contents and analysis of humification indexes: humification ratio (HR), humification index (HI), degree of polymerization (DP) and percentage of HA ($P_{HA}$).

## 2. Methods

### 2.1. Bioreactor and windrow

Sewage sludge composting was conducted in a two-stage system: the first stage an aerated bioreactor (1 $m^3$), and the second a periodically (weekly) turned windrow (0.8 $m^3$). The entire volume of the bioreactor enabled loading about 500 kg of composting materials. The bioreactor was equipped with an aerated system that enabled regulation of air supply quantity. In the reactor, there were two temperature sensors PT 100, coupled with LED displays, which allowed determination of temperature with 0.1 °C precision. The sensors were mounted at two levels, i.e. at depths of 7 and 63 cm from the top of the bioreactor (Fig. 1).

The bioreactor was covered with a 10 cm layer of mature compost to insulate it and minimize water loss. The cover also acted as a biofilter to minimize odor emissions. Air was supplied to the bioreactor at 1–1.5 L/kg min, and moisture content in the raw mixture was 70%. The amount of air was adjusted depending on the temperature of composted mass.

**Table 1**
Share of individual components in the feedstock.

| Series No. | Sewage sludge (% w/w) | Inocluation (% w/w) | Wood chips (% w/w) | Rape straw (% w/w) | Grass (% w/w) |
|---|---|---|---|---|---|
| 1 | 60 | 3 | 15 | 22 | 0 |
| 2 | 60 | 3 | 15 | 7 | 15 |

Two series were performed. In both series content of sewage sludge, inoculation and structural materials in the form of wood chips were constant. However, series varied in the proportion of rape straw and grass came from the lawns located in the sewage treatment plant (Table 1).

The composting process lasted 217 d:10 d of decomposition of organic materials and sanitation in the bioreactor, and 207 d of compost maturation in the windrow.

### 2.2. Characterization of feeding materials

Dewatered sewage sludge was taken from a municipal wastewater treatment plant, working in SBR system. The sewage sludge did not contain bacteria of *Salmonella* spp. or eggs of parasites of *Ascarsis*, *Trichuris* or *Toxocara* spp.

Owing to low porosity, high humidity and low C:N ratio, the sludge was mixed with lignocellulosic materials. The investigations were conducted at a constant content of sewage sludge (60%), inoculation (3%) and structural materials in the form of wood chips (15%). The proportion of lignocellulosic materials (e.g. rape straw and grass) varied (Table 1).

Composted materials differed in moisture, OM, N and fiber (Table 2). Rape straw contained the most cellulose. The highest lignin content was in wood chips; however, as structural material these were not composted and after the process were recovered and reused.

Mixing of sludge (with high humidity and high N) with materials of lower humidity and lower N caused obtaining reduced moisture content and increased OM/N ratio in the feedstock (Table 3).

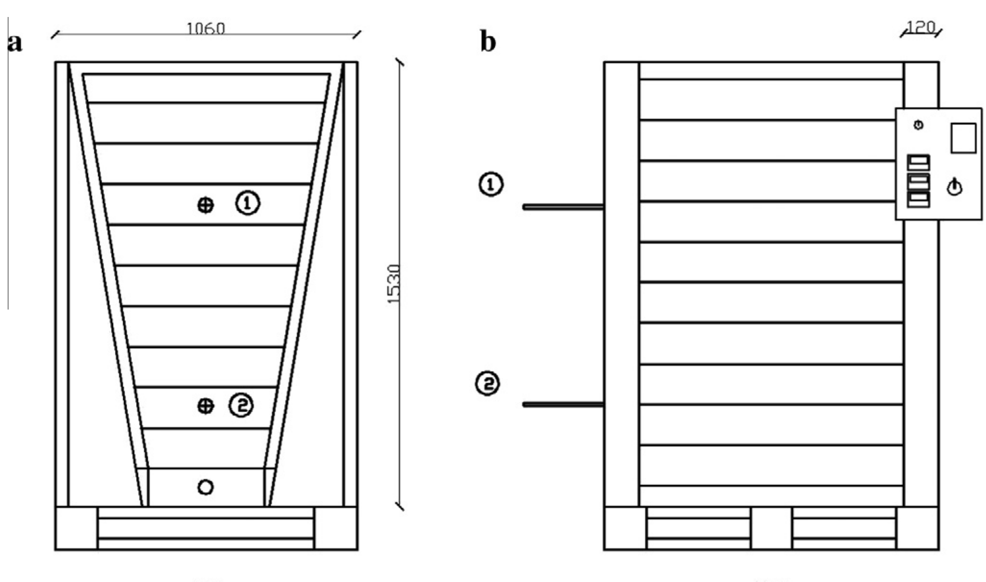


**Fig. 1.** Scheme of the bioreactor (1, 2 temperature sensors) (a) front of the bioreactor (b) side of the bioreactor.