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Short Communication

Distribution of C and N in soluble fractionations for characterizing the respective biodegradation of sludge and bulking agents

Ling Zhao, Xiao-Yi Wang, Wei-Mei Gu, Li-Ming Shao, Pin-Jing He *

Institute of Waste Treatment and Reclamation, State Key Laboratory of Pollution Control and Resources Reuse, College of Environmental Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China

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ABSTRACT

This study utilized C and N distribution in different soluble fractionations instead of the routine C/N ratio to characterize the respective biodegradation of sludge and bulking agents in bio-drying or composting. For sludge, C was mainly distributed (31.8%) in the neutral detergent soluble and water insoluble fraction (SOL), whereas it was mainly distributed in the cellulose-like fraction (CEL) for straw (39.5%) and sawdust (45.8%). A large proportion of N was in the 35 °C water-soluble fraction (W35 °C) for sludge (34.0%) and straw (52.5%), while for sawdust it was in the lignin-like fraction (LIG; 49.4%). For sludge, the C and N loss were mainly contributed by W35 °C (36.9% and 52.4%). The other fractions also contributed a lot. For straw, 22.4% of C and 89.8% of N lose in W35 °C. The hemicellulose-like (HEM) and CEL fraction also gave a large contribution to C loss (28.5% and 40.1%), while contributing little to N loss.

1. Introduction

Sludge composting and the recently developed process, sludge bio-drying, are two important strategies for sewage sludge disposal (Navaee-Ardeh et al., 2010). Aerobic biodegradation of organics is the main mechanism of these processes (Abouelwafa et al., 2008; Velis et al., 2009). Many previous studies about composting and bio-drying have given an insight to the biodegradation characteristics of the mixture of sludge and bulking agents (Trémier et al., 2009). Although an initial intense degradation of organic matter was present at the 0–3 days, the total degradation of the mixture that generally no more than 16 days is always very low, at around 30% (Yanez et al., 2009; Zhao et al., 2010).

So during this process, what does the duration of the biodegradation depend? Almost all studies focused on the organic matters change of the mixture rather than each material. Here the change of sludge and the bulking agents such as straw or sawdust should be clarified. The second problem is that the C/N ratio of total solid is often used to describe changes in organic matter. It was regarded to indicate the nutrient balance of the composters. However, it fails to show the bio-accessibility of C and N and their decomposition patterns (Shin and Jeong, 1996; Cousins et al., 2009). Also, it is difficult to investigate what hinders further degradation after a fast initial peak.

The modified Van Soest method (Van Soest and Wine, 1967) is usually used for materials of plant origin and fractionates the organic matter into soluble components, hemicellulose, cellulose and lignin with a sequential extraction method (Mottet et al., 2010). The distribution of C and N in every fraction is used to predict the potential C and N mineralization in soil (Lashermes et al., 2010). It has been reported by Doublet that 27% of sludge C was in the 100 °C water-soluble fraction and 42% in the neutral detergent soluble fraction. During the composting, C and N in hemicellulose-like and cellulose-like fractions decreased significantly (Doublet et al., 2010).

The first extraction step of the modified Van Soest method is in 100 °C water. If the water-extractable fractions in 35 °C were combined with the modified Van Soest method, it is expected to be a more effective strategy to show the C and N degradation in each fraction. The objectives of this study are: (1) to characterize the respective behavior of the raw materials including sludge, straw and sawdust during bio-drying or composting using separate incubation; (2) to investigate the change of C, N in different soluble fractionations and compare with the total solid C/N ratio to give an insight into the mechanism of the different biodegradability of the materials.

2. Methods

2.1. Dewatered sewage sludge and bulking agents

The dewatered sewage sludge was obtained from a local municipal wastewater treatment plant in Shanghai, China. The plant treats 75,000 $m^3\ d^{-1}$ of wastewater (93% domestic and 7% industrial

* Corresponding author. Tel./fax: +86 21 6598 6104.
E-mail address: solidwaste@tongji.edu.cn (P.-J. He).

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Table 1
The characteristics of the raw materials.

	Sludge	Straw	Sawdust
Moisture content (%)	82.9 ± 0.65	69.4 ± 0.25[a]	68.5 ± 0.19[a]
VS (%, dry basis)	62.6 ± 0.14	91.5 ± 0.05	96.4 ± 0.11
TC (%, dry basis)	30.8 ± 0.32	45.6 ± 0.15	50.4 ± 0.37
TN (%, dry basis)	5.11 ± 0.16	1.04 ± 0.04	0.27 ± 0.002
TOC (%, dry basis)	29.3 ± 0.35	44.9 ± 0.15	49.8 ± 0.41
TKN (%, dry basis)	5.05 ± 0.10	0.81 ± 0.04	0.27 ± 0.002

[a] Straw and Sawdust has been soaked with the supernatant of mixed sludge.

sewage) using an anaerobic–anoxic–oxic (A^2O) process. Sludge was dewatered by centrifugation with the addition of organic flocculating agents. Chopped rice straw of 0.5–3.0 mm and powdery sawdust were used as bulking agents. Sawdust was the by-product of a wood working manufacturing facility. The characteristics of the raw materials are presented in Table 1.

2.2. Aerobic degradation

The moisture content of straw and sawdust was adjusted using the supernatant of mixed sludge from the aeration tank, which simultaneously functioned as an inoculant. The adjusted moisture content of the straw and sawdust was 69.4% and 68.5%, respectively. To ensure aerobic respiration, the sludge was spread on the inner wall of the reactors to form a thin layer. Intermittent aeration using an air blower and a gas-flow meter was performed to supply O_2. The frequency was 10 min run/50 min stop. The air-flow rate was approximately 0.05 $m^3\,h^{-1}\,kg^{-1}$ (wet basis), which was selected to ensure aerobic conditions and simultaneously minimizing the moisture loss. The incubation lasted for 16 days and the materials were sampled at different intervals for analysis. All the tests were replicated.

2.3. Sequential extraction protocol

After air drying at 60 °C, the samples were fractionated by a modified version of the method proposed by Van Soest. A step of water extraction at 35 °C for 6 h (W35 °C) was performed before 100 °C extraction to clarify the characterization of water-extractable fractions and their influence on biodegradability. The hot water soluble fraction (W100 °C) was extracted with distilled water at 100 °C for 30 min. Another sample was extracted with a neutral detergent solution (NDS) at 100 °C for 60 min as an additional soluble fraction. Similarly, the other samples were sequentially extracted by acid detergent solution (ADS) and 72% H_2SO_4. The five solvents were chosen according to their gradual dissolving capacity. The fraction being soluble in NDS and insoluble in water (35 and 100 °C) was named as SOL. The fraction being soluble in ADS and insoluble in NDS was named as hemicellulose-like (HEM). The fraction being soluble in 72% H_2SO_4 and insoluble in ADS was named as cellulose-like (CEL). The residue not soluble in 72% H_2SO_4, which including lignin, cell, cutin and suberin represents the lignin-like fraction (LIG).

The distribution of C and N within the different fractions was measured and expressed as a percentage of the total C (TC) and total N (TN), respectively. The biochemical fractions were expressed as g·100 g^{-1} DM (dry matter).

2.4. Analytical methods

Determination of the moisture content of samples was conducted by drying at 105 °C for 24 h. Volatile solids (VS) content was analyzed by heating at 550 °C for 6 h. The C and N content of the materials were analyzed using an element analyzer (Vario EL III, Elementar, Germany). The total organic carbon (TOC) was analyzed using a TC/TN analyzer with a solid sample module (TOC-V CPN, TNM-1, SSM-5000A, SHIMADZU, Japan). The total Kjeldahl nitrogen (TKN) was analyzed using an auto Kjeldahl determination system (8400, FOSS, Sweden).

3. Results and discussion

3.1. Mass and C, N distributions in different soluble fractionations

According to Table 1, the TOC and TKN of the materials are almost equal to their respective TC and TN values. So the TC and TN were used to evaluate the change of C and N. The modified Van Soest method makes it possible to characterize the bio-accessibility of different organic biochemical fractions. The mass, C and N distributions of sludge, straw and sawdust are shown in Fig. 1. The fraction of W35 °C was much larger in sludge (17.5%) and straw (12.6%) than in sawdust (2.35%). The sludge was characterized by a high neutral detergent soluble fraction (50.8%). Straw was rich in CEL (35.6%) and sawdust was rich in CEL (31.4%) and LIG (43.0%). Similarly, C was mainly distributed in neutral detergent soluble fraction for sludge (31.8%), while in CEL for straw (39.5%) and sawdust (45.8%). As for sludge N, 34.0% was extracted by 35 °C water and 65.4% was extracted by NDS. A large proportion of straw N (52.5%) was distributed in W35 °C, while 49.4% of sawdust N was in LIG. Aoyama also observed that in manure and city refuse compost, most N was located in the fine and water-soluble fractions (Aoyama, 1985).

Table 2 shows that the routine C/N ratios of sludge, straw and sawdust based on total solid were 6.03, 43.8 and 187, respectively, whereas, the C/N ratios of W35 °C for the three materials were all much smaller than the routine ones. For sludge, the C/N ratio of SOL was highest. And for straw, the one of CEL and HEM were high.

3.2. The C and N loss kinetics of the materials based on total solid

The first separate incubation of sludge and bulking agents gave a clearer profile relating to the change of each material. According to the traditional method, the total solid C and N loss kinetics can be used to evaluate the organic matters change, as Fig. 2 shows. During the process, the C and N loss rate profiles corresponded with the first-order reaction (Zhang et al., 2010). The substrate utilization rate, r, can be represented by first-order reaction kinetics [Eq. (1)]:

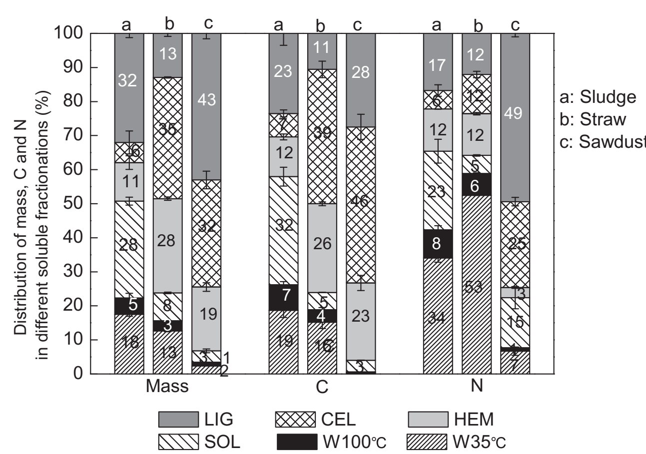

Fig. 1. Mass and C, N distributions in different soluble fractions.