Journal of Environmental Management 207 (2018) 366–377

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Evolution of various fractions during the windrow composting of chicken manure with rice chaff

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ARTICLE INFO

Article history:
Received 19 July 2017
Received in revised form
6 November 2017
Accepted 7 November 2017

Keywords:
Chicken manure
Windrow composting
Organic matter (OM)
Water-soluble fractions (WSF)
Hydrolytic enzymes

ABSTRACT

Different fractions during the 85-day windrow composting were characterized based on various parameters, such as physiochemical properties and hydrolytic enzyme activities; several technologies were used, including spectral scanning techniques, confocal laser scanning microscopy (CLSM) and ^{13}C Nuclear Magnetic Resonance Spectroscopy (^{13}C NMR). The evaluated parameters fluctuated strongly during the first 3 weeks which was the most active period of the composting process. The principal components analysis (PCA) results showed that four classes of the samples were clearly distinguishable, in which the physiochemical parameters were similar, and that the dynamics of the composting process was significantly influenced by C/N and moisture content. The ^{13}C NMR results indicated that O-alkyl-C was the predominant group both in the solid and water-soluble fractions (WSF), and the decomposition of O-alkyl-C mainly occurred during the active stage. In general, the various parameters indicated that windrow composting is a feasible treatment that can be used for the resource reuse of agricultural wastes.

1. Introduction

In recent years, large quantities of livestock and poultry manures containing rich organic nutrients have been improperly utilized, leading to the serious contamination of air, water bodies and soil (Hanselman et al., 2003). Organic wastes are considered valuable soil conditioners that can provide various nutrients to crops, and the application of organic manures to soil effectively improves long-term soil fertility and productivity (Goyal et al., 2005). However, Rashad et al. (2010) noted that immature manures can be phytotoxic due to the insufficient biodegradation of OM in the composts when directly applied to soil. Therefore, it is necessary to develop efficient technologies for converting these manures into valuable composts. Composting is widely adopted to achieve nutrients recycling, kill pathogens and stabilize the organics (Wang et al., 2014) and can transform various forms of OM into mature amendments for soils (Zhou et al., 2015). Windrow composting, which produces compost by piling biodegradable OM into long rows, is increasingly the focus of international attention because it has been characterized as being rapid and highly efficient (Gould et al., 2013). These rows are generally turned by a turning machine equipped with a crushing jaw to improve oxygen content and porosity, decrease the moisture content, and redistribute hotter and cooler portions of the pile.

Despite these advantages, the degradation of lignocellulosic materials in the substrates is hindered by two primary technical bottlenecks, namely the recalcitrant characteristics of lignocelluloses and the lack of highly active lignocellulases. Lignocellulosic biomass degradation primarily depends on the activities of various lignocellulolytic enzymes including cellulase, hemicellulase and lignin-degrading-related enzymes, which work synergistically to degrade the lignocellulosic fractions (Liu et al., 2013). Cellulases are responsible for the degradation of cellulose, and they are composed of endoglucanases (EGs), cellobiohydrolases (CBHs) and β-glucosidases, and hemicellulase is a collective term for enzymes that are in charge of the hydrolysis of xylan polymers, such as xylan, lichenin and laminarin. Various microbe species including fungal and bacterial ones have the ability to degrade lignocellulose by secreting several of these hydrolysing enzymes into the outside environment

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https://doi.org/10.1016/j.jenvman.2017.11.023
0301-4797/

(Linton and Greenaway, 2004). Various thermophilic microorganisms play key roles during the composting process, and these microbes are responsible for the degradation of different organic compounds by secreting various extracellular hydrolytic enzymes under aerobic, moist and self-heating conditions (Vargas-Garcia et al., 2010). Therefore, Monitoring the presence and activity of various hydrolytic enzymes during composting process can help to understand the composting dynamics and efficiency.

Different hydrolytic enzymes secreted by various microorganisms can catalyze the hydrolysis of carbonaceous and nitrogenous compounds to form WSF, which is a useful parameter to evaluate the evolution of the composting process, thus improving our understanding of the entire windrow composting process (Malerba et al., 2014). In many cases, WSF interconvert rapidly due to the complex physiochemical and biological reactions, because most of the biochemical transformations of the organic compounds take place in this fraction (Wang et al., 2014). As a major component of WSF, Water-soluble carbon which mainly consists of sugars, hemicellulose, phenolic substances and other easily biodegradable compounds is one of the most readily biologically active parameters able to define compost stability (Castaldi et al., 2008). Water soluble nitrogen including ammonium, nitrate and other soluble nitrogen compounds is also a critical parameter used to evaluate the level of the nitrogen compounds evolution (Chen et al., 2003). Based on the above reasons, determination of the WSF of the compost is critical for obtaining deeper insights into organic compound transformations that occur during the windrow composting process, and improving the products quality and effective downstream.

The abundance of biochemical changes occurring during the composting process and the methods used to monitor different parameters have resulted in a certain difficulty to assess the maturity of composts. What is particularly clear is that current knowledge about the conversation process of chicken manure with rice chaff is limited. Several methods for biochemical analysis have been used to characterize the changes in WSF during the composting process, such as CLSM, Fourier transform infrared (FTIR), ^{13}C NMR and Excitation-emission-matrix fluorescence (EEM-FL). Currently, one of the optimal approaches is multiple fluorescence labeling combinding CLSM, which enables the study of composition, architecture and function of the biofilm formed during the composting process at the microscopic level (Yu et al., 2011). Broad-scale analysis using FTIR spectroscopy is used to analyze the composition of soil and compost samples, which are rich in aliphatic, phenolic, aromatic and polysaccharide compounds, and this method can track the dynamics of various functional groups during the composting process (El Ouaqoudi et al., 2015). Unlike other approaches, ^{13}C NMR is more helpful to quantify the abundances of carbon-containing functional groups in the samples, and the chemical shift ranges were divided into four groups based on the resonance regions: alkyl C (0–45 ppm), O-alky C (45–110 ppm), aromatic C (110–160 ppm), and carboxyl and carbonyl C (160–190 ppm) (Wang et al., 2015). EEM spectroscopy is extensively used to determine protein-like, humic acid-like and fulvic acid-like fractions, which will help to track the conversation dynamics of various functional substrates (Provenzano et al., 2001).

In light of the above considerations, the main objective of this investigation was to track the dynamics of solid and WSF during the windrow composting of chicken manure and rice chaff. For this reason, the physiochemical characteristics including composition and several stability related parameters and the presence of several hydrolytic enzymes activities were determined. Furthermore, multiple techniques, such as FTIR, CLSM and ^{13}C NMR, were combined to study the succession and changes the WSF during the windrow composting process, which will convey something interesting and unique to the readers and help them better understand the functionality of composting.

2. Materials and methods

2.1. Composting experiments

The composting experiments were carried out at Jiangyin from Aug 19, 2015 to Nov.12, 2015, and the average temperature was 28 °C with the rainfall of 600 mm during the composting process. Chicken manure and rice chaff (75/25; v/v) were used as raw materials to track the conversation dynamics of various functional groups, which would be critical for revealing the transformation mechanisms of various organic matters. After being well mixed, the raw materials were made into a long strip with the following dimensions: 20 m × 2 m × 1.5 m (length × width × height), and the well mixed raw materials (0 day) were used as CK in the subsequent experiments. The chicken manure was collected from a chicken farm (Changzhou Lihua Livestock and Poultry Co., Ltd. Changzhou, China), and the rice chaff was obtained from Tianniang Technology Co., Ltd. (Changshu, China). The physicochemical properties of the raw material are shown in Table 1.

The temperature of the pile was measured at different locations (surface, 10–15 cm; middle, 25–30 cm; and innermost layer, 25 cm from the base of the pile) using a portable temperature detector (JM222HI; range, −50 to 100 °C; precision: 0.3 °C). The pile was aerated using a turning machine, and sampling was performed at 1, 3, 7, 14, 21, 28, 35, 45, 55, 65, 75 and 85 d. Approximately 1000 g of subsamples from each pile were taken and then divided into two equal parts; one part was preserved at 4 °C for extraction of WSF, fluorescent staining and enzyme activities, and the other was ground and sieved (100 mesh) after air drying.

2.2. Chemical analyses

Moisture content was measured using gravimetric weight loss method drying at 105 °C for approximately 24 h; electrical conductivity (EC) and pH were determined using a conductivity meter (LF91, Wiss. Techn. Workstation, Germany) and a pH electrode (PB-10, Sartorius, Germany) (1:6, w/v, fresh sample/water ratio). Organic carbon (OC) and total nitrogen (TN) were measured using an elemental analyzer (Vario EL III, Elementar Analysensysteme GmbH, Germany). Volatile solid (VS) content was measured based on the weight loss after 2 h at 550 °C in a muffle furnace. All results are expressed per dry weight of material and are presented as the means and standard error of three replicates.

WSF was obtained following Wang et al. (2014) with some modifications: 20 g of each fresh sample was suspended in 200 mL deionized water (1:10, w/v) and shaken on a horizontal shaker for 24 h at 25 °C, after which the mixture was centrifuged

Table 1
Physicochemical properties of the raw materials for composing.

Samples	Organic C (%)	Total N (%)	C: N	NH_4^+ (mg·g^{-1} dw)	NO_3^- (mg·g^{-1} dw)	P (mg·g^{-1} dw)	K (mg·g^{-1} dw)	Moisture (% fw)	pH
Chicken manure	28.63 ± 0.67	3.28 ± 0.52	8.73	9.05 ± 0.26	0.58 ± 0.08	12.37 ± 0.81	18.25 ± 1.07	72.63 ± 0.72	7.86
Rice straw	45.37 ± 0.74	1.26 ± 0.43	36.01	0.54 ± 0.08	0.13 ± 0.02	1.45 ± 0.51	13.64 ± 3.42	10.26 ± 0.51	6.75

Moisture content is expressed as a% on a fresh weight (fw) basis; dw means dry weight.