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Biochemical changes and GHG emissions during composting of lignocellulosic residues with different N-rich by-products

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ABSTRACT

Nitrogen availability plays a critical role in the biodegradation of organic matter during composting. Although the optimal initial C/N is known to be around 25–30, the chemical form in which N is present influences microbial activity and therefore degradation rate and gaseous losses. This study was conducted to evaluate the influence of N availability on the composting of a mixture of lignocellulosic materials. Three composting piles were made of a mixture of wheat straw and cotton waste, each pile containing different N-rich animal by-products. The evolution of the main physico-chemical parameters was monitored (temperature, pH, electrical conductivity, C/N, NH_4^+, NO_3^-, water soluble C and N) as well as the enzymatic activity related to the cycle of the main nutrients (β-glucosidase, protease, alkaline phosphatase and fluorescein diacetate hydrolysis). Additionally, fluxes of CO_2, CH_4 and N_2O emitted from the composting piles were measured by the closed-chamber technique. Cumulative CO_2 emissions were fitted to five different kinetic models with biological significance to C mineralization data. The application of the different N-rich residues had a significant effect on the C and N dynamics during composting. However, most enzymatic activities followed similar patterns in the three piles. The major CO_2 fluxes were recorded during the thermophilic phase, showing a direct relationship with temperature peaks. No CH_4 fluxes were detected for any of the composting piles during the whole trial, whereas low N_2O emissions were found at the early beginning and during the maturation stage.

1. Introduction

Lignocellulose, and more specifically its lignin fraction, has long been supposed to be a major source of stable C in soil (Trigo and Ball, 1994). Karlen et al. (2009) have recently summarized the benefits provided by crop residues on ecosystem services, alerting that the removal of lignocellulosic residues from soil would have strong adverse impact on soil quality and bio-available C storage.

For many years lignocellulosic residues have been successfully composted (Cornfield, 1958) with the aim of decreasing their high C/N, eliminating pathogens and, in general, improving their stability and quality as soil amendments. Due to their high C/N, the supply of an exogenous N supplement is necessary to optimize the composting process (Eiland et al., 2001; Pandey et al., 2009). Recently, several investigators have proposed the use of animal by-products for composting (Alburquerque et al., 2009; Barrena et al., 2009). Some animal by-products are commercially available as certified organic fertilizers. They derive from slaughterhouses, food processing, leather or pharmaceutical industries and their co-composting with lignocellulosic residues may become a valuable recycling strategy.

The evolution of different forms of N during composting depends on the material that provides N to the mixture (Sánchez-Monedero et al., 2001) and has a major impact on microbial and chemical evolution (Eiland et al., 2001; Cayuela et al., 2009), organic matter degradation rate (Sánchez-Monedero et al., 2001; Pandey et al., 2009) and gaseous losses (Sánchez-Monedero et al., 2001; Noble et al., 2002).

Concerns over climate change have resulted in a range of efforts to regulate and reduce emissions and replenish the storage of stable C in soil (C sequestration). Compost application to soil is a possible option to reach such goal, but the net benefits of composting on C sequestration are currently widely debated. Some researchers warned that C sequestration could be frequently offset by elevated emissions of other potent greenhouse gases (GHG) such as N_2O and CH_4 during the composting process. Hence, the number of scientific articles studying GHG emissions during composting has

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increased within the last years (Jäckel et al., 2005; Andersen et al., 2010; Sánchez-Monedero et al., 2010; Hao et al., 2011; Park et al., 2011).

Whereas CH_4 is mostly produced during the bio-oxidative phase of composting, N_2O can be released at different stages. Some studies state that the highest N_2O emissions are produced at the beginning of the process, during the thermophile phase (Parkinson et al., 2004), while other studies establish that it is mainly produced during the mesophile and maturation periods (Hao et al., 2004). Although contradictory, these results are not paradoxical considering the great diversity of organic materials used for composting, the different composting systems, the measurement parameters and the climate conditions under which the experiments were performed. Amlinger et al. (2008) gave some recommendations for minimizing GHG emissions during composting, which encompass a C/N higher than 25, high proportion of bulking materials and optimized moisture that, in general, correspond with the basic rules of an appropriate compost management.

This study aimed at identifying the differences in N and C dynamics, biochemical evolution and GHG emissions produced during composting when different N sources are added to the same lignocellulosic mixture. Our hypothesis was that different N availability influences the degradation rate, microbiological activity and therefore gas losses during composting.

2. Materials and methods

2.1. Materials used

Two lignocellulosic residues: wheat straw (WST) and cotton cardings (CTC) were used for the preparation of three composting mixtures. Four N-rich by-products with different N availability: meat bone meal (MBM), hydrolysed leather (HYL), blood meal (BLM) and horn and hoof meal (HHM) were selected among commercially available animal by-products. The main chemical characteristics of the residues are given in Table 1.

2.2. Composting experiment

Three composting piles were prepared with an identical mixture of WST and CTC (2:1 on a fresh weight basis) adding different N-rich animal by-products in each pile. The relative proportions were adjusted to give an initial C/N of about 30.

Table 1
Main chemical characteriztics of residues used in the composting experiment.

	Lignocellulosic materials		Animal by-products			
	WST	CTC	MBM	HYL	BLM	HHM
DM (%)	89.1	88.0	93.0	91.1	90.8	84.0
TOC (%)	49.6	45.2	46.0	42.0	49.3	51.3
TN (%)	0.25	1.48	11.08	13.21	15.61	17.01
TOC/TN	198.4	30.5	4.2	3.2	3.2	3.0
pH	6.47	6.22	5.90	5.19	6.68	7.46
EC (dS m^{-1})	0.13	5.93	4.58	15.07	7.80	2.18
WSC (g kg^{-1})	15.7	37.8	60.5	34.7	118.9	13.7
WSN (g kg^{-1})	0.8	2.4	17.1	23.2	37.9	5.0
WSC/WSN	19.6	15.8	3.5	1.5	3.1	2.7
NH_4^+ (mg kg^{-1})	66	303	359	6360	122	1887
K (g kg^{-1})	4.0	15.5	2.9	3.8	6.9	1.1
Ca (g kg^{-1})	1.9	20.5	69.0	39.1	1.1	4.2
Mg (g kg^{-1})	0.8	4.1	1.4	1.0	0.2	0.5
P (g kg^{-1})	0.4	2.0	27.1	13.1	2.0	1.7
Fe (mg kg^{-1})	166	524	337	786	2144	1665

WST: wheat straw; CTC: cotton cardings; MBM: meat bone meal; HYL: hydrolyzed leather; BLM: blood meal; HHM: horn and hoof meal.
DM: dry matter; TOC: total organic carbon; TN: total nitrogen; EC: electrical conductivity; WSC: water soluble carbon; WSN: water soluble nitrogen.

Pile 1: 62% WST + 32% CTC + 6% MBM (dry weight basis).
Pile 2: 62% WST + 32% CTC + 6% HYL (dry weight basis).
Pile 3: 62% WST + 32% CTC + 6% mixture of BLM and HHM (1:1) (dry weight basis).

Water was added to adjust moisture to 65%. The mixtures (around 100 kg moist weight each) were placed in 300 dm^3 polyethylene composting bins (95 cm long, 60 cm width, 53 cm height) provided with a perforated bottom to allow passive aeration. Moreover, four turnings were made during the composting period (at 14, 23, 37, and 59 d). At each turning event, the composting mixture was taken out of the composting bin and thoroughly mixed to homogenize the mass, reactivate the process and avoid compaction. Temperature was monitored daily by inserting a thermocouple into five different points of the pile. The composting bins were placed in the open, under a shelter built for protection from the wind and the rain. No leaching losses were produced during the entire process.

Samples (1 kg, fresh weight) were collected at seven different stages (0–92 d) during the composting process by mixing 20 subsamples (approx 50 g each) obtained from different locations in the piles. An aliquot of the composite sample was immediately extracted for the measurement of ammonium, while the remainder was air dried and ground to 0.5 mm.

2.3. Chemical and biochemical analysis

Dry matter (DM) content was determined by drying at 105 °C to constant weight. Ash concentration was determined by loss on ignition at 550 °C for 8 h. Total nitrogen (TN) and organic carbon (TOC) were analyzed by automatic elemental microanalysis (NA 1500 Carlo Erba Instruments, Milan, Italy).

Water soluble C (WSC) and N (WSN) were determined after extraction with deionized and degassed water at 1:20 (w:v) ratio for 2 h at room temperature, by using a TOC-VCSN analyzer (Shimadzu Corporation, Kyoto, Japan). Ammonium was extracted from fresh samples with 0.5 M K_2SO_4 at 1:20 (w:v) ratio for 30 min at room temperature and determined by a colorimetric method based on Berthelot's reaction at 660 nm (Sommer et al., 1992).

Nitrate was extracted by shaking a sample with 0.5 M K_2SO_4 at 1:20 (w:v) ratio for 30 min at room temperature. The concentration of NO_3^- in the extracts was determined by reading the absorbance at 220 nm and subtracting the interference caused by organic matter at 275 nm (Gross et al., 1999). Protease, β-glucosidase, alkaline phosphatase and fluorescein diacetate hydrolysis (FDA) activities were determined according to Alef and Nannipieri (1995).

2.4. Greenhouse gases sampling and measurement

A static chamber technique was used to measure fluxes from the surface of the compost piles (Beck-Friis et al., 2000; Sommer and Moller, 2000; Sommer et al., 2004; Park et al., 2011). The chamber used for this investigation was specifically designed to hermetically close the composting bins and concentrate the gas emitted from the whole pile in a short time interval. It had a pyramidal shape (volume 35 dm^3) with an outlet in the vertex for direct gas sampling.

It is known that the high inner temperature of a windrow cause an upward airflow ("chimney effect") so that the main part of emissions leaves the windrow at the top (Sommer et al., 2004; Andersen et al., 2010). The chamber was positioned on the composting bin only during the sampling time. For excessively long measuring periods, the gas emission rate significantly decreases, so preliminary measurements were made with identical