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Changes in the microbial communities during co-composting of digestates ☆

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ABSTRACT

Anaerobic digestion is a waste treatment method which is of increasing interest worldwide. At the end of the process, a digestate remains, which can gain added value by being composted. A study was conducted in order to investigate microbial community dynamics during the composting process of a mixture of anaerobic digestate (derived from the anaerobic digestion of municipal food waste), green wastes and a screened compost (green waste/kitchen waste compost), using the COMPOCHIP microarray. The composting process showed a typical temperature development, and the highest degradation rates occurred during the first 14 days of composting, as seen from the elevated CO_2 content in the exhaust air. With an exception of elevated nitrite and nitrate levels in the day 34 samples, physical–chemical parameters for all compost samples collected during the 63 day process indicated typical composting conditions. The microbial communities changed over the 63 days of composting. According to principal component analysis of the COMPOCHIP microarray results, compost samples from the start of the experiment were found to cluster most closely with the digestate and screened compost samples. The green waste samples were found to group separately. All starting materials investigated were found to yield fewer and lower signals when compared to the samples collected during the composting experiment.

1. Introduction

In order to reduce negative impacts on the environment, the European Landfill Directive (1999/31/EC) states that by 2016, the disposal of biodegradable municipal waste should be reduced by 75%, compared to 1995 values. Composting of municipal, agricultural and industrial wastes is among the most commonly used biowaste treatment options employed across Europe. Another increasingly used technology is anaerobic digestion (AD), whereby organic substrates are converted into a methane rich biogas, suitable for heat and electricity production. A digestate remains at the end of the process, which contains both undegraded and non-degradable organic compounds as well as nutrients (Körner et al., 2010). Recently, the combination of both anaerobic digestion and composting for biowaste treatment has been increasingly promoted. The advantage is the combined generation of energy and material products – biogas and compost as a soil improver. This combination increases the efficiency of bioresource utilisation. However, before integrating an anaerobic digestion unit into an existing composting facility, the economic framework and technical setup has to be evaluated and optimised.

Process optimisation is important for both anaerobic digestion and composting facilities, as well as for plants integrating both processes. Digestates are often characterised by a high biogas potential, indicating an inefficient anaerobic digestion process. For instance, Linke et al. (2007) reported a remaining biogas potential in digestates from a dry fermentation plant using maize silage and turkey manure from approximately 25 NL biogas per kg digestate fresh matter. For comparison, the actual biogas production during anaerobic digestion was around 100 NL biogas per kg fresh input. Balsari et al. (2010) investigated the methane yields from the mechanically separated solid fractions of digestates from 6 biogas plants and found variations from 50 L methane production per kg volatile solids of up to around 210 L. They suggested reuse in the biogas plant to increase the overall process efficiency.

The remaining, undegraded organic products can also be subjected to composting, although composting could as well be conducted with more efficiently treated digestates. The composting of

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digestates differs from the composting of common substrates, since the digestates are often characterised by very low dry matter content (dry matter content of 20–26% for digestates investigated by Linke et al. (2007). In a study conducted by Bustamante et al. (2013), the composting of pig slurry digestate with different bulking agents was investigated, and stable and mature composts were obtained. A similar study by Bustamante et al. (2012) used the solid fraction of a digestate from the anaerobic co-digestion of cattle slurry and silage, with or without vine shoot prunings as a bulking agent, in a composting experiment. The composts obtained showed adequate degrees of stability and maturity, suitable physical properties for use as growing media, and were capable of the suppression of the plant pathogen *Fusarium oxysporum* f. sp. *melonis*.

Aerobic conditions are needed for composting processes (Körner, 2008), and the addition of aerobic microorganisms from co-substrates can help in the composting process. Mixing composts with drier and more bulky materials is necessary to provide suitable composting conditions. Since microorganisms play a major role in anaerobic digestion as well as composting, knowledge on the behaviour and dynamics of microbial communities is necessary for any kind of process optimisation (Sundberg et al., 2011). This is because the presence of different bacteria can positively or negatively affect the composting process, and modification of the type and amount of input materials can change the microbial communities, and the composting process. In recent years, the microbiology of composting processes has been heavily investigated, both with classical (Kausar et al., 2011; Lv and Yu, 2013), physiological (Mondini and Insam, 2005) and molecular (Tiquia et al., 2005; Franke-Whittle et al., 2009; Yamamoto et al., 2011) approaches. However, knowledge regarding the microbial communities involved in anaerobic digestion is still limited, and that of combined processes is even more limited.

A microarray targeting plant, animal and human pathogens, plant disease suppressive bacteria, as well as microorganisms that have been previously reported in the composting process, was developed by Franke-Whittle et al. (2005, 2009). The COMPOCHIP microarray allows the quick detection of many different microorganisms in a single test, and has been used in several composting studies (Danon et al., 2008; Cayuela et al., 2009; Sundberg et al., 2011, 2013; Fritz et al., 2012).

The aim of this study was to investigate the changes in microbial communities in a composting experiment using the COMPOCHIP microarray. Three input substrates were selected: a municipal food waste digestate, a green waste and a screened compost produced from green waste and kitchen waste. Of interest was to determine how the microbial composition would evolve during the composting process.

2. Materials and methods

2.1. Substrates for composting

Fresh green waste (*Gw*), screened compost (*Co*) and digestate (*Dig*) were used as input substrates for the experiment (Table 1). *Gw* was produced from wood chips, yard trimmings and tree cuttings and taken from a composting facility. It was shredded to a size appropriate for laboratory reactor trials. *Gw* was expected to contain ubiquitous microrganisms. *Co* was produced from separately collected organic waste (green waste and kitchen waste) by means of an enclosed reactor technology, following the guidelines of the German biowaste ordinance (BioAbfV, 1998). After composting, it was screened and the 20–50 mm fraction was used in this study. *Co* was used in order to introduce a variety of aerobic microorganisms into the mixture, which are typical for composting. *Dig* was produced by an industrial mesophilic anaerobic digestion process. The digester was fed with the liquid fraction derived from shredded food waste separated by means of a mash-separator, as well as with oil residues from the olive oil industry. The mixing ratio (food waste liquid: olive residues) was 9:1 (fresh weight). *Dig* was expected to contain a predominantly anaerobic microbial flora.

A mixture of the three substrates was manually prepared for the composting experiment. One of the purposes of the mixing was to introduce a significant share of microorganisms from all fractions into the composting substrate. The water content of the *ISM* (initial starting material) was adjusted to 64% by the addition of the anaerobic digestate, as seen in Table 1.

2.2. Composting and sampling

Composting was carried out in an insulated 100-L steel tank composting unit, which is described in detail in Körner (2008). The schematic set-up of the whole unit, including peripheral equipment is presented in Fig. 1. In total, three composting experiments were carried out, each in duplicate. All experiments showed the typical course of composting. Samples from one of the experiments was chosen for investigation of the microbial consortia.

The composting reactor was filled with 55.6 kg fresh matter (fm) of the substrate mixture and was aerated at a rate of 100 L h^{-1}. For that purpose, compressed air was bubbled from underneath the mixture to oxygenate the substrate. The gas flows were manually adjusted and continuously monitored during composting by means of a mass flow meter. The composting period lasted 63 days and during this period, the substrate mixture was turned three times (after 8, 20 and 34 days). Turnings were performed by emptying the reactor and manually mixing the material. Three representative samples were taken after mixing and reactors were refilled. The samples were either analysed directly, or stored (4 °C and −20 °C) for future analyses.

The weight losses along the composting process were determined by weighing the whole reactor on each turning day. Furthermore, the amounts of leachate were measured upon turning. The temperature profiles of the substrate mixtures during composting and of the gaseous phase above the substrate were monitored several times a day with PT 100 temperature probes. No additional heat was provided. The exhaust air was captured at the top of the reactor and sent to a waste gas treatment system. The gas treatment system consisted of a condenser and an acid trap, and the condensate and acidic solution were analysed on demand

Table 1
Physical and chemical parameters of original substrates and of the mixture used in the composting experiment.

Sample	Amount (% fm)	Amount (% dm)	Dry matter (% fm)	pH	NH_4^+ (mg L^{-1})	Total water soluble N (mg L^{-1})	TKN (% dm)	TOC (% dm)
Green waste (*Gw*)	52.40	64.40	48	5.54	69	235	1.94	37.05
Compost (*Co*)	21.50	33.30	60	7.74	74	309	1.55	25.75
Digestate (*Dig*)	26.20	2.30	6	7.79	513	654	1.40	39.65
Initial substrate mixture (*ISM*)	–	–	36	7.10	120	266	1.87	34.63

Note: fm – fresh matter; dm – dry matter; TKN – Total Kjeldahl nitrogen; TOC – Total organic carbon; NO_3^- and NO_2^- – under detection limit (0.05 mg L^{-1} eluate); NH_4^+ and Total water soluble N refer to the content in the eluate (both are water soluble fractions).