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# Comparison of solid-state anaerobic digestion and composting of yard trimmings with effluent from liquid anaerobic digestion

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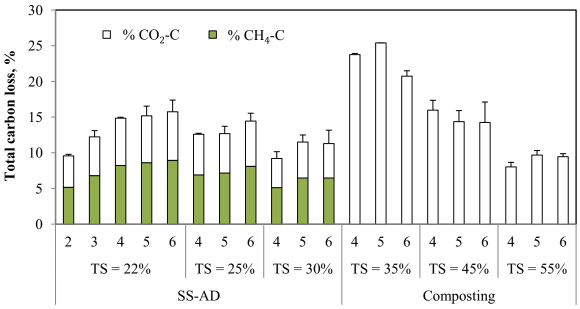
## HIGHLIGHTS

- Solid-state anaerobic digestion (SS-AD) and composting were compared.
- High total solids content negatively affected performance of SS-AD and composting.
- The preferred feedstock/effluent ratio for SS-AD was 4–6.
- The total carbon loss during composting was up to 50% greater than that in SS-AD.
- Both SS-AD and composting generated nutrient-rich (N, P, K) end products.

## GRAPHICAL ABSTRACT

Solid-state anaerobic digestion (SS-AD) and composting of yard trimmings with effluent from liquid anaerobic digestion were conducted at TS content of 22–30% and 35–55%, respectively. Carbon loss was compared at feedstock to effluent ratio ranged from 4 to 6. The greatest total carbon loss was observed at 35% TS in composting, which was about 50% higher than that in SS-AD; while, using SS-AD, more than half of the degraded carbon was converted to methane as a renewable energy carrier.



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## ABSTRACT

Solid-state anaerobic digestion (SS-AD) and composting of yard trimmings with effluent from liquid AD were compared under thermophilic condition. Total solids (TS) contents of 22%, 25%, and 30% were studied for SS-AD, and 35%, 45%, and 55% for composting. Feedstock/effluent (F/E) ratios of 2, 3, 4, 5, and 6 were tested. In composting, the greatest carbon loss was obtained at 35% TS, which was 2–3 times of that at 55% TS and was up to 50% higher than that in SS-AD. In SS-AD, over half of the degraded carbon was converted to methane with the greatest methane yield of 121 L/kg $VS_{feedstock}$. Methane production from SS-AD was low at F/E ratios of 2 and 3, likely due to the inhibitory effect of high concentrations of ammonia nitrogen (up to 5.6 g/kg). The N–P–K values were similar for SS-AD digestate and compost with different dominant nitrogen forms.

## 1. Introduction

Municipal solid waste (MSW) has become one of the largest environmental concerns in recent decades due to its increasing quantity. Besides recycling, there are globally four methods used

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for the management of MSW: landfilling, incineration, composting, and anaerobic digestion (AD). In 2012, about 228 million tonnes of MSW were generated in the United States, and yard trimmings were the third largest component comprising 13.5% (USEPA, 2012). However, current policy aims to divert yard trimmings from landfills and incinerators due to potential pollution. More than 50% of yard trimmings were diverted by composting in the U.S. (USEPA, 2012). Furthermore, yard trimmings may also serve as a feedstock of anaerobic digestion for renewable biogas production (Liew et al., 2012). However, AD or composting using yard trimmings may be hindered by high carbon to nitrogen (C/N) ratios (Forster-Carneiro et al., 2008; Li et al., 2011a). This problem can be solved by introducing a nitrogen-rich amendment.

AD is a widely used technology that produces biogas, a renewable fuel, through decomposition of organic matter in the absence of oxygen by consortia of microorganisms. Most commercial digesters in the United States are liquid anaerobic digestion (L-AD) systems that contain less than 15% total solids (TS) and are fed with manure, sewage sludge, or food waste (USEPA, 2013). The by-product of L-AD, also known as L-AD effluent, usually has a high water content and is expensive to transport long distances. Thus energy intensive dewatering processes are often employed. However, L-AD effluent is rich in nitrogen and active microbial consortia, which could likely improve the rate of yard trimmings conversion in both composting and anaerobic digestion (Xu et al., 2013).

With respect to digesting yard trimmings, solid-state anaerobic digestion (SS-AD), which operates with TS content higher than 15%, is a better option than L-AD, because problems of floating and stratification of fibrous materials in L-AD can be addressed in SS-AD (Chanakya et al., 1999). Furthermore, due to the lower water content, the by-product of SS-AD, also known as digestate, is much easier to transport than the L-AD effluent (Li et al., 2011a). Recently, SS-AD has been tested as a method to use L-AD effluent as an inoculum and nitrogen source for the production of methane from yard trimmings (Liew et al., 2012). L-AD effluent was found to be a better inoculum source for SS-AD than aerobic waste activated sludge, rumen fluid, or manure, as it provided a balanced microbial consortium with greater methanogenic activity (Forster-Carneiro et al., 2007; Kim and Speece, 2002). In addition, digestion at thermophilic temperatures (55 °C) has been reported to be more efficient in decomposing organic wastes and destroying pathogens than at mesophilic temperatures (37 °C) (Shi et al., 2013). One concern with thermophilic SS-AD is its high energy demand to maintain process temperature and sensitivity of thermophilic AD microbial communities to environmental disturbances, such as pH (Shi et al., 2013).

In contrast, composting is an aerobic biological process to degrade organic matters by consortia of microbes. It has also been used to treat L-AD effluent by adding bulking agents such as sawdust and produces a solid saleable end product (Bustamante et al., 2013). Composting generally proceeds through two phases: initial and thermophilic, followed by a mesophilic maturation or curing (Fogarty and Tuovinen, 1991; Liang et al., 2003). Upon completion of these phases, most pathogens have been destroyed (Grewal et al., 2006), thereby converting L-AD effluent and bulking agents to a solid soil amendment (Bustamante et al., 2013). The key factors affecting the performance of composting process are aeration, TS content, and C/N ratio (Fogarty and Tuovinen, 1991). TS contents in the range of 30–40% (60–70% moisture content) have been reported to provide maximum microbial activities (Liang et al., 2003). When L-AD effluent is used to provide nitrogen for composting without additional buffers or nutrient supplements, the feedstock to effluent (F/E) ratio is the sole parameter that determines the pH, alkalinity, and C/N ratio of the mixture to be composted. The optimal C/N ratio for composting has been reported to be in the range of 26–35 (Fogarty and Tuovinen, 1991).

SS-AD and composting have different advantages and disadvantages in treating solid wastes. SS-AD is more complicated and requires a larger investment compared to composting (Li et al., 2011a). However, SS-AD produces renewable biogas as a fuel, while composting does not (Walker et al., 2009).The composting process usually requires a larger area and can emit odor, while SS-AD usually operates under controlled systems with a relatively smaller area (Bustamante et al., 2013). Both SS-AD and composting of yard trimmings have been reported in the literature (Chanakya et al., 1999; Fogarty and Tuovinen, 1991; Liew et al., 2012); however, no side-by-side comparison of thermophilic SS-AD and composting of yard trimmings with L-AD effluent has been reported. The objectives of the present study were to: (1) compare the rate of biogas/$CO_2$ production from thermophilic SS-AD/composting of yard trimmings amended with L-AD effluent; (2) evaluate the effects of TS content and F/E ratio on the performance of SS-AD and composting; and (3) compare carbon loss, degradation of organic compounds, and the fertilizer values of the end products generated from SS-AD and composting.

## 2. Methods

### 2.1. Yard trimmings and L-AD effluent

Yard trimmings consisting of wood chips (30% w/w), lawn grass (20% w/w), and maple leaves (50% w/w) were used as the feedstock for SS-AD and composting tests. Yard trimmings have a more balanced C/N ratio of around 30 than that of the individual component (Liew et al., 2012). Wood chips, lawn grass, and maple leaves were obtained in June, 2011 from the Ohio Agricultural Research and Development Center (OARDC) campus in Wooster, OH, USA. These feedstocks were dried at 40 °C for 48 h in a convection oven (Precision Thelco Model 18, Waltham, MA, USA) to a moisture content of less than 10%, then ground with a hammer mill to pass through a 9 mm screen sieve (Mighty Mac, MacKissic Inc., Parker Ford, PA, USA), and stored in air-tight containers. Effluent and centrifuged effluent were collected from a mesophilic liquid anaerobic digester that processed municipal sewage sludge (KB BioEnergy, Inc., Akron, OH, USA). Centrifuged effluent was produced with a D5LL solid bowl decanter centrifuge (ANDRITZ AG, Graz, Austria) at the facility and was used to achieve the designed TS contents for composting tests. Both effluents were stored in air-tight buckets at 4 °C. Prior to use, they were acclimated at 55 °C for 1 week.

### 2.2. SS-AD

A full factorial design with three TS contents (22%, 25%, and 30%) and three F/E ratios (4, 5, and 6) was used for the SS-AD experiments. Two additional F/E ratios of 2 and 3 were included at the TS content of 22%. The yard trimmings, deionized (DI) water, and effluent were mixed using a hand-mixer (Black & Decker, 250-watt mixer, Towson, MD, USA), and then loaded into 1 L glass reactors and incubated for up to 45 days in a 55 ± 0.3 °C incubator (BioCold Environmental, Inc., Fenton, MO, USA). Triplicate reactors were tested for each condition. Effluent without any feedstock addition was used as a control. Biogas was collected in 5 L Tedlar gas bags (CEL Scientific, Santa Fe Springs, CA, USA) connected to the outlets of each reactor. Biogas composition and volume were measured every 2–3 days.

### 2.3. Composting

For the composting experiments, a similar full factorial design with three TS contents (35%, 45%, and 55%) and three F/E ratios (4, 5, and 6) was used. The yard trimmings, effluent, and/or