Science of the Total Environment 557–558 (2016) 355–362

Contents lists available at ScienceDirect

Science of the Total Environment

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

Decomposition and carbon storage of hardwood and softwood branches in laboratory-scale landfills

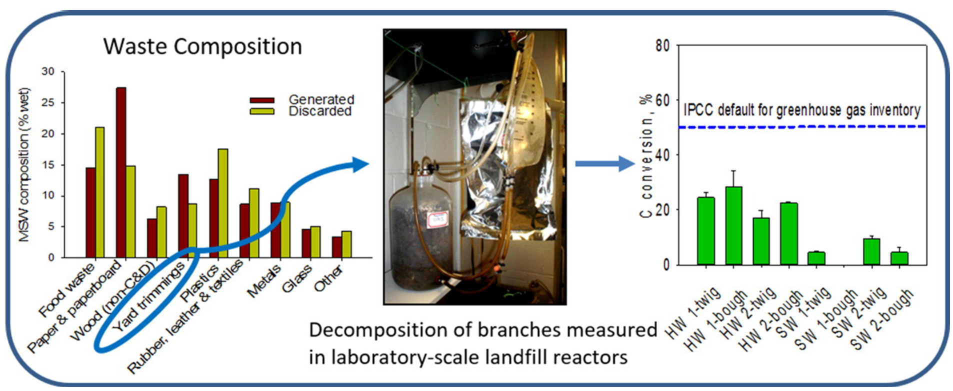
Xiaoming Wang [a,b,*], Morton A. Barlaz [b]

[a] Key Laboratory of Three Gorges Reservoir Region's Eco-Environment under Ministry of Education, Chongqing University, Chongqing 400044, China
[b] Department of Civil, Construction, and Environmental Engineering, Campus Box 7908, North Carolina State University, Raleigh, NC 27695-7908, United States

HIGHLIGHTS

- Characterized biodegradation of branches under simulated but optimized landfill conditions
- Observed varied biodegradation between HW and SW branches with different diameters
- Inhibitory extractives were observed on boughs or twigs of some branch species.
- CH_4 yield and carbon storage factors presented for use in landfill related inventories.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 February 2016
Received in revised form 9 March 2016
Accepted 13 March 2016
Available online xxxx

Editor: Simon Pollard

Keywords:
Landfills
Municipal solid waste
Hardwood and softwood branches
Anaerobic decomposition
Carbon storage

ABSTRACT

Tree branches are an important component of yard waste disposed in U.S. municipal solid waste (MSW) landfills. The objective of this study was to characterize the anaerobic biodegradability of hardwood (HW) and softwood (SW) branches under simulated but optimized landfill conditions by measuring methane (CH_4) yields, decay rates, the decomposition of cellulose, hemicellulose and organic carbon, as well as carbon storage factors (CSFs). Carbon conversions to CH_4 and CO_2 ranged from zero to 9.5% for SWs and 17.1 to 28.5% for HWs. When lipophilic or hydrophilic compounds present in some of the HW and SW samples were extracted, some samples showed increased biochemical methane potentials (BMPs). The average CH_4 yield, carbon conversion, and CSF measured here, 59.4 mL CH_4 g^{-1} dry material, 13.9%, and 0.39 g carbon stored g^{-1} dry material, respectively, represent reasonable values for use in greenhouse gas inventories in the absence of detailed wood type/species data for landfilled yard waste.

1. Introduction

The U.S. EPA estimates that yard trimmings or green waste, which consists of branches, grass clippings and leaves, accounts for 8.7% of the 149 million metric tons of discarded municipal waste (after recycling and composting) in the U.S. in 2012 (U.S. EPA, 2014). Recently,

* Corresponding author at: Key Laboratory of Three Gorges Reservoir Region's Eco-Environment under Ministry of Education, Chongqing University, Chongqing 400044, China.
E-mail address: wangxiaoming@cqu.edu.cn (X. Wang).

http://dx.doi.org/10.1016/j.scitotenv.2016.03.091
0048-9697/

a considerably higher estimate of landfill disposal was reported (262 million metric tons) and this later estimate is based on actual disposal data and likely more accurate (Powell et al., 2015). Thus, while the quantity of waste disposed in landfills is uncertain, it is apparent that despite the presence of 3453 yard trimming composting operations reported in 44 states in the U.S. (Platt and Goldstein, 2014), significant quantities of yard trimmings are disposed in municipal solid waste (MSW) landfills. While data on the composition of yard trimmings is limited, Oshins and Block (2000) reported that yard trimmings contain up to 30% branches in the U.S. Another study showed that branches accounted for 19.5% of garden waste in Denmark (Boldrin and Christensen, 2010).

When biodegradable organic matter is disposed in landfills, some fraction is converted to carbon dioxide (CO_2) and methane (CH_4), the latter of which is both a potent greenhouse gas and a source of energy when captured for beneficial use. As yard trimmings are not completely biodegradable, the residual organic carbon is stored in a landfill and carbon storage has been shown to constitute a significant component of a landfill carbon balance (Christensen et al., 2009).

There is limited information on the biodegradation of branches in landfills. Eleazer et al. (1997) reported a CH_4 yield of 62.6 mL CH_4 g^{-1} dry branches, which has been widely used as a proxy for all wood disposed in landfills. More recent research suggests that this proxy is misleading. Wang et al. (2011) showed that the value reported by Eleazer et al. (1997) was significantly higher than the CH_4 yields for both hardwood (HW) and softwood (SW) lumber that was tested under similar conditions. This inconsistency is not surprising as the recent data show that there are differences in biodegradability that can be attributed to differences in wood species and the Eleazer study was based on one mixture of branches recovered from a yard waste composting facility.

The objective of this study was to measure the anaerobic biodegradability of both HW and SW branches in laboratory-scale simulated landfill reactors. This work included measurement of CH_4 yields and carbon storage factors (CSFs) as well as the loss of cellulose, hemicellulose, and organic carbon. Both HW and SW branches were studied based on the results of previous work that showed differences in biodegradability between HW and SW, which is consistent with differences in both the structure and chemical composition of HW and SW (Wang et al., 2011). In addition, branches with different diameters were tested to explore whether there is variability in the extent of biodegradation between large and small diameter branches. There are both practical and mechanistic reasons to study branch biodegradation as a function of diameter. Practically, branches in yard waste are likely to consist of both relatively small diameter trimmings as well as larger diameter branches associated with fallen trees. Mechanistically, there may be differences within even one species of wood in characteristics such as the content of sapwood and heartwood as well as the extractives content (Fengel and Wegener, 1984). As trees age, a zone of dead cells is formed (i.e., heartwood) and this zone is enriched in wood extractives, including aliphatic compounds, terpenes, and phenolic substances relative to the rest of the tree (Eriksson, 1990; Fengel and Wegener, 1984). The components of extractives in some species have been shown to exert toxicity to methanogens (Fengel and Wegener, 1984; Sierra-Alvarez and Lettinga, 1990; Wang et al., 2011), which may inhibit the conversion of wood to CH_4 and CO_2. As such, the impact of extractives on CH_4 generation was also investigated by using biochemical methane potential (BMP) tests.

2. Materials and methods

2.1. Experimental design

The anaerobic biodegradability of HW and SW branches was measured in triplicate 8-L reactors under simulated landfill conditions operated to maximize the rate and extent of decomposition. Each substrate was inoculated with decomposed residential waste as an inoculum and triplicate control reactors were operated to measure background CH_4 from the inoculum. Tests were conducted with both twigs and boughs (larger diameter branches) for two HW and two SW samples. Incubation conditions included initial inoculation with anaerobically decomposed residential MSW, leachate neutralization and recirculation, the periodic addition of nitrogen (N) and phosphorus (P) to maintain these nutrients above 100 mg NH_3-N/L and 5 mg PO_4-P/L, respectively, and incubation in a room at about 37 °C.

To evaluate the extent to which the extractives affect CH_4 generation, BMP tests were conducted on samples both before and after removal of lipophilic or hydrophilic extractives by Soxhlet extraction with toluene and ethanol (2:1, v/v) or with the deionized (DI) water.

2.2. Materials

Samples of branches were collected from commonly distributed tree species as they would be discarded prior to contamination with other MSW components. Oaks and pines were selected for study as they are among the tree species commonly distributed in North America (USGS, 2013). Initially, samples of hardwood (HW 1-white oak, *Quercus alba*) and softwood (SW 1-loblolly pine, *Pinus taeda*) were collected from the North Carolina State University (NCSU) campus to explore the variability between HW and SW. A second series of reactors was initiated with another set of hardwood (HW 2-willow oak, *Quercus phellos*) and softwood (SW 2-white pine, *Pinus strobus*) to explore the variability between species within HW or SW.

Branches from each species were divided into two subsamples based on their diameters, i.e., twigs (<2.54 cm) and boughs (>7.62 cm), to explore biodegradation as a function of branch diameter. All samples were shredded with a slow-speed, high-torque shredder (Shredpax AZ-7H) to obtain a sample size of 2 to 5 cm, and stored at 4 °C until used.

The inoculum for initiation of decomposition was obtained from a ~300 L drum that contained decomposed residential solid waste. The drum was initially filled with fresh residential waste that was decomposed under anaerobic conditions. The fresh waste was collected from a local MSW transfer station and represents residential waste that would be discarded in MSW landfills.

2.3. Reactor construction, filling, and operation

The procedures for reactor construction, filling and operation have been described previously (Wang et al., 2011) and are summarized here. The sample and the inoculum were mixed and added to reactors in a 3:1 (v/v) ratio. Sufficient DI water was added initially to ensure the generation of leachate for recirculation and DI water was added periodically to maintain about 500 mL of leachate due to sample removal. The leachate was collected in an intravenous bag (Baxter Healthcare, Deerfield, IL), neutralized as necessary and then recirculated three to five times a week throughout the incubation period. The concentrations of N and P were measured approximately monthly and adjusted to the aforementioned target concentrations with NH_4Cl and KH_2PO_4 as necessary. The pH and chemical oxygen demand (COD) were measured weekly to monthly.

Gas was collected in flex-foil gas bags (SKC Corp., Houston, TX) and both the volume and composition were measured every 1 to 2 weeks based on the volume produced. The reactors were operated until either no more CH_4 was produced or an extrapolation of gas production data (as described below) indicated that the reactors had produced more than 95% of the CH_4 that would ultimately be generated. When reactors were dismantled, the solid residues were dried, weighed, and analyzed for cellulose, hemicellulose, lignin, and organic carbon.