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Performance of green waste biocovers for enhancing methane oxidation

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ABSTRACT

Green waste aged 2 and 24 months, labeled "fresh" and "aged" green waste, respectively, were placed in biocover test cells and evaluated for their ability to oxidize methane (CH_4) under high landfill gas loading over a 15-month testing period. These materials are less costly to produce than green waste compost, yet satisfied recommended respiration requirements for landfill compost covers. In field tests employing a novel gas tracer to correct for leakage, both green wastes oxidized CH_4 at high rates during the first few months of operation – 140 and 200 g/m^2/day for aged and fresh green waste, respectively. Biocover performance degraded during the winter and spring, with significant CH_4 generated from anaerobic regions in the 60–80 cm thick biocovers. Concurrently, CH_4 oxidation rates decreased. Two previously developed empirical models for moisture and temperature dependency of CH_4 oxidation in soils were used to test their applicability to green waste. Models accounted for 68% and 79% of the observed seasonal variations in CH_4 oxidation rates for aged green waste. Neither model could describe similar seasonal changes for the less stable fresh green waste. This is the first field application and evaluation of these empirical models using media with high organic matter. Given the difficulty of preventing undesired CH_4 generation, green waste may not be a viable biocover material for many climates and landfill conditions.

1. Introduction

Landfills contribute about 22% of total anthropogenic methane (CH_4) emissions (USEPA, 2010). To reduce CH_4 atmospheric emissions, porous media engineered to enhance biodegradation of CH_4, i.e., biocovers, may be placed on landfill surfaces to enhance CH_4 oxidation, which has been suggested as a low-cost technology to mitigate CH_4 emissions (IPCC, 2007). Biocovers may be particularly well suited for hot spots of CH_4 emission found on landfill covers (Abichou et al., 2006), or biowindows, which are small treatment zones on landfill surfaces engineered to enhance CH_4 oxidation (Scheutz et al., 2011).

Research on the oxidation of CH_4 in landfill cover soils and landfill biocovers has been conducted for more than 15 years (e.g., Boeckx et al., 1996; Chanton and Liptay, 2000; Czepiel et al., 1995; De Visscher et al., 1999; Einola et al., 2009, 2007; Gebert et al., 2003; Scheutz et al., 2009b; Wang et al., 2011; Whalen et al., 1990). These laboratory and field studies quantified the effect of pH (Hanson and Hanson, 1996; Hilger et al., 2000; Scheutz and Kjeldsen, 2004), nutrient limitations (Boeckx et al., 1996; De Visscher et al., 1999; Scheutz and Kjeldsen, 2004), and extracellular polymeric substances (EPS) (Hilger et al., 1999; Wilshusen et al., 2004a,b), for example, on CH_4 oxidation rates in landfill soils and biocovers. Temperature and moisture content are two environmental factors also shown to affect CH_4 oxidation (Boeckx et al., 1996; Borjesson et al., 2004; Chanton et al., 2008; Dever et al., 2011; Einola et al., 2007; Gebert et al., 2003; Park et al., 2009). Although CH_4 oxidation can occur over 5–50 °C, the optimum temperature for methanotrophs is ~30 °C (Borjesson et al., 1998; Park et al., 2005; Scheutz and Kjeldsen, 2004; Stein and Hettiaratchi, 2001; Whalen et al., 1990). Moisture content also affects CH_4 oxidation: excess water may limit oxygen diffusion from the

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atmosphere, reducing rates of CH_4 oxidation (Scheutz et al., 2009a). Too little water, though, also reduces methanotrophic activity (Czepiel et al., 1996; Stein and Hettiaratchi, 2001; Whalen et al., 1990).

In two recent studies, Spokas and Bogner (2011) and Abichou et al. (2011) developed models describing the effect of these two environmental factors – moisture and temperature – on CH_4 oxidation using landfill cover soils from the field. Both sets of model equations are shown in Table 1. The relative rate of CH_4 oxidation, R_α, due to moisture (α = SWP, soil water potential, or VWC, volumetric water content) or temperature ($\alpha = T$, temperature) ranges between 0, with moisture or temperature completely limiting, and 1, no moisture or temperature limitations. Because Spokas and Bogner (2011) developed their models using data from six different landfill cover soils and a much larger number of total samples than Abichou et al. (2011) (single landfill soil), Spokas and Bogner (2011) models are believed more generally applicable to a wider variety of landfill cover materials. Both models were developed for low organic matter soils and their applicability to green waste with high organic matter (>30%) is untested.

Landfill biocovers are engineered to have a suitable porosity for gas transport and exchange (Humer and Lechner, 1999), and appropriate water holding capacity to support microbial activities (Abichou et al., 2011; Huber-Humer et al., 2009). Typically, biocovers consist of compost, compost/woodchip or compost/soil mixtures that are believed to enhance CH_4 oxidation when compared to traditional clay soil covers (Barlaz et al., 2004; Abichou et al., 2006; Stern et al., 2007). Because of the expense of these materials, they may be best suited for application in hot spots (Abichou et al., 2006) or biowindows (Scheutz et al., 2011), where high fluxes of CH_4 occur through biocover treatment media that cover a small fraction of the landfill surface. Green waste (or yard waste) may be a viable alternative organic material for such biocovers, since this is a readily available waste at many landfills and is less costly than compost. Here, some aging of the green waste is anticipated before application, resulting in properties similar to composts. Green waste is a significant component of solid waste streams in the United States, and was estimated to account for 13.7% of 243 million metric tons of generated municipal solid waste in 2009 (USEPA, 2009). Green waste contains significant amounts of organic matter, which is important for sustaining CH_4 oxidation in biocovers (Humer and Lechner, 1999). On the other hand, high organic matter content increases water retention and may result in high water contents that inhibit O_2 diffusion from the atmosphere, thus decreasing aerobic activity. Moreover, CH_4 might be generated due to anaerobic degradation of organic matter (Scheutz et al., 2009b). Thus, there is some uncertainty about how green waste may perform as a biocover material, which is undoubtedly related to the stability of the organic matter as well as other characteristics of this material. Finally, while models were developed to predict the effect of temperature and moisture on CH_4 oxidation in landfill cover soils with low organic matter (Abichou et al., 2011; Spokas and Bogner, 2011), these models have not been tested for their utility in predicting the performance of green waste or other high organic matter media. Thus, an assessment of model predictions for such media in field settings is valuable.

In this work we address the following questions regarding the use of green waste as a landfill cover material: How effective is green waste for oxidizing CH_4 after relatively short periods of stabilization? Are CH_4 generation and respiration from non-composted green waste significant? Can existing models for the influence of temperature and moisture on methanotrophic activity developed for mineral soils account for seasonal variations of CH_4 oxidation in green waste with high organic matter?

2. Materials and methods

2.1. Biocover cell design

Two pilot-scale, simulated biocover test cells were constructed at the Yolo County Central Landfill (N38 35.451 W121 41.5, Woodland, CA). The climate at this site is Mediterranean with an average yearly temperature of 11.7 °C; the warmest (average 21.7 °C) and the coolest (average 3.9 °C) months appear in July and January, respectively. The average annual precipitation is 101.1 cm, with the maximum precipitation usually occurring in January with limited rainfall during summer months.

A schematic of the biocover test cells is shown in Fig. 1. Each above-ground cell was 2.4 m by 1.8 m by 1.2 m (length × width × height) and was lined with a 0.2 mm thick reinforced polyethylene liner that retained biocover materials and prevented liquid and gas movement across the side and bottom boundaries. At the bottom of each cell 0.3 m-thick gravel was used to collect leachate and inject landfill gas (LFG). Leachate was collected from a drain system at the bottom of the gravel layer, while twelve 6.35 mm ID High Density Polyethylene (HDPE) tubes allowed LFG injection and distribution into the gravel layer. Each gas injection tube was connected to an external needle valve that was adjusted to distribute LFG flow evenly across the bottom of each cell. Above the gravel layer a 90-cm thick layer of fresh or aged green waste described further below was placed. Thick green waste layers were installed because settlement was anticipated to be large in the first few months after placement, and our goal was to test the utility of thick green waste layers that might last considerably longer than thinner (~30-cm) material. Because of settlement, the initial 90-cm thick green waste was quickly reduced to 65–75 cm thickness. Both biocovers were thinned by removing the top 15–20 cm of each biocover cell at the end of field testing to assess the impact of green waste thickness on performance (see Supporting Information).

2.2. Biocover materials

Two types of green wastes, green material as defined in Title 14, California Code of Regulations, Section 17852(a) (21), were used to fill the biocover test cells. Biocover cell 1 was filled with aged green waste, primarily yard trimmings consisting of leaves, branches, and grass received at the Yolo County Central Landfill that was placed on landfill slopes and allowed to age for approximately 24 months. Biocover cell 2 was filled with fresh green waste, i.e., green waste that was received at the landfill two months before cell packing. Both aged and fresh green wastes were screened through a 76 mm mesh before packing the two adjacent biocover test cells in January 2009. Measurements of biocover settlement were performed intermittently between January 2009 and August 2010. Dry bulk densities were measured in March 2009 and estimated on subsequent dates using settlement data. Samples were also collected from both biocover test cells to quantify material properties, respiration rates, and water retention properties: sampling procedures and measurement techniques are described in Supporting Information.

Because the composition of the initial green wastes, i.e., grass, leaves, etc., before decomposition was not quantified, differences in material properties in Biocover cells 1 and 2 may not be due to age alone. As will be shown below, the major differences between the two green wastes were organic matter content and stability. Because there was no replicate of either green waste biocover cell, inferential statistics were not used in comparing the data from each, which is discussed in Supporting Information.