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Does vegetation affect the methane oxidation efficiency of passive biosystems?

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ABSTRACT

It is often reported in the technical literature that the presence of vegetation improves the methane oxidation efficiency of biosystems; however, the phenomena involved and biosystem performance results are still poorly documented, particularly in the field. This triggered a study to assess the importance of vegetation in methane oxidation efficiency (MOE). In this study, 4 large scale columns, each filled with sand, topsoil and a mixture of compost and topsoil were tested under controlled conditions in the laboratory and partially controlled conditions in the field. Four series of laboratory tests and two series of field tests were performed. 4 different plant covers were tested for each series: *Trifolium repens* L. (White clover), *Phleum pratense* L. (Timothy grass), a mixture of both, and bare soil as the control biosystem. The study results indicated that up to a loading equal to 100 g $CH_4/m^2/d$, the type of plant cover did not influence the oxidation rates, and the MOE was quite high ($\geqslant$95%) in all columns. Beyond this point, the oxidation rate continued to increase, reaching 253 and 179 g $CH_4/m^2/d$ in laboratory and field tests respectively. In the end, the bare soil achieved as high or higher MOEs than vegetated biosystems. Despite the fact that the findings of this study cannot be generalized to other types of biosystems and plants and that the vegetation types tested were not fully grown, it was shown that for the short-term tests performed and the types of substrates and plants used herein, vegetation does not seem to be a key factor for enhancing biosystem performance. This key conclusion does not corroborate the conclusion of the relatively few studies published in the technical literature assessing the importance of vegetation in MOE.

1. Introduction

Methane (CH_4) is the main greenhouse gas emitted by landfills and represents 18% of the global anthropogenic CH_4 emissions (Bogner et al., 2007). Passive methane oxidation biosystems (PMOBs) are considered one of the most cost-effective technologies for mitigation of CH_4 emissions from landfills (IPCC, 2007). In recent years, considerable research has focused on improving these biosystems. They are usually made up of a sequence of soil layers, including a gas distribution layer (GDL) and a methane oxidation layer (MOL). The performance of passive methane oxidation biosystems (PMOBs) depends on several environmental factors, including temperature, degree of water saturation within the soils, organic matter content of the MOL, several other soil properties and characteristics and, last but not least, the presence of vegetation.

According to Reay et al. (2005), vegetation is a key determinant of biotic CH_4 oxidation. Despite this finding, its importance on the efficiency of PMOBs is still relatively poorly documented, particularly in the field, where, to the authors' knowledge, no technical papers have been published so far. This paper focuses on evaluating the importance of vegetation on CH_4 oxidation efficiency within engineered biosystems tested on a landfill and in the laboratory.

Documentation on CH_4 oxidation and emissions from several vegetated mediums (wetland rice fields, freshwater marshes, forest soil, grassland or cultivated soil) is widely available (Ding et al., 2004; Jia et al., 2001; Keppler et al., 2006; Nouchi et al., 1990; Reay et al., 2005; Watanabe et al., 1997). The effect of vegetation has been related to several bio-physico-chemical processes such as: diffusion, biological controls and CH_4 transport through the root system. Indeed, transport through vascular plants has been identified as one of the main pathways of CH_4 exchange between the atmosphere and the soil (Chanton, 2005; Chanton et al.,

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1989; Ding et al., 2004; Schütz et al., 1989). Chanton (2005) reported methane consumption by the roots of two aquatic plants: *pontederia cordata* and *sagittaria lancifolia*. Vascular plants can help promote the diffusion of O_2 from the atmosphere to the rhizosphere through the arenchyma system. In addition, plant roots can produce exudates and release them to the rhizosphere, which may substantially influence chemical or biological soil properties in ways that can help the biogeochemical process of methane oxidation (Hilger et al., 2000; Stralis-Pavese et al., 2004; Tanthachoon et al., 2008). Moreover, in a study of the effect of 3 plant species on the CH_4 oxidation capacity in forest soils, Reay et al. (2005) suggested that the presence of nitrogen-fixing (N-fixing) plants, such as alder, may result in large reductions in potential CH_4 oxidation in soils. Popp et al. (2000) reported on the other hand that there were no significant differences between CH_4 oxidation measured for bulk peat of a non-vegetated site core and the control vegetated site cores for the same time period. Thereby, quantitative estimates of methane oxidation in several vegetated mediums may be related to differences in the systems studied such as the plant species present (King et al., 1990; Van der Nat et al., 1997).

Recent research on engineered biosystems for landfills suggests that plants would positively contribute to CH_4 oxidation (Bohn et al., 2010; Hilger et al., 2000; Reichenauer et al., 2011; Wang et al., 2008). It is reported that vegetation can improve the air-filled capacity of soils through the formation of secondary macro-pores by spreading roots. In addition, vegetation controls moisture infiltration by means of plant evapotranspiration. Finally, plant growth may also provide nutrients for methanotrophs by root exudates and debris of dead plants and thereby increase oxidation efficiency. Some potential negative effects of vegetation on CH_4 oxidation include the potential for plant roots to create preferential channels for CH_4 emissions, and their competition for O_2 due to root respiration (Wang et al., 2008). Plants debris may also lead to O_2 competition with bacteria degrading the debris and thus decreasing methane oxidation efficiency. However, the actual integrated effect of plant species on the methane oxidation process in landfill covers remains poorly documented in the technical literature, particularly in relation to engineered biosystems for landfills tested under field conditions.

In order to verify the validity of the hypothesis that the type of vegetation may affect the CH_4 oxidation efficiency of a biosystem, the following 3 types of plants were tested under the controlled conditions prevailing in the laboratory and under the partially controlled conditions of the Saint-Nicéphore landfill, QC, Canada: (1) White clover (*Trifolium repens* L.), which is a leguminous plant; (2) Timothy grass (*Phleum pratense* L.); and (3) a mixture of White clover and Timothy grass. An unplanted biosystem served as control.

The research reported in this paper included a series of 4 laboratory tests performed in sequence and 2 field tests. Each test was comprised of 4 columns containing the same sequence of materials and one of the 4 vegetation covers presented above. The methane oxidation efficiencies (MOE) of the columns were determined for several methane loadings, while temperature and degree of water saturation profiles were obtained throughout the tests by a data acquisition system.

2. Materials and methods

2.1. Experimental set-up

2.1.1. Laboratory set-up

Four columns measuring $0.61 \times 0.46 \times 0.52$ m were built for the laboratory-scale experiment. A schematic of their design is presented in Fig. 1. The methane oxidation layer (MOL) of the biosystems was constituted of the following materials, from the bottom up: a 0.30-m layer of fine sand, a 0.075-m layer of topsoil, and a 0.075-m layer of topsoil enriched with compost (5% dry weight). The gas distribution layer (GDL) that is usually constructed under the MOL was substituted by an empty space. The GDL and MOL were separated by a 2-cm thick perforated plastic plate covered by a fine wire mesh. Seepage water was collected at the bottom of the column and evacuated through an outlet.

The columns were set in an explosion-proof laboratory. A lighting system was installed in order to foster plant growth. It consisted of 100-Watt fluorescent lamps controlled by an electronic unit that was set to provide the required number of hours of light

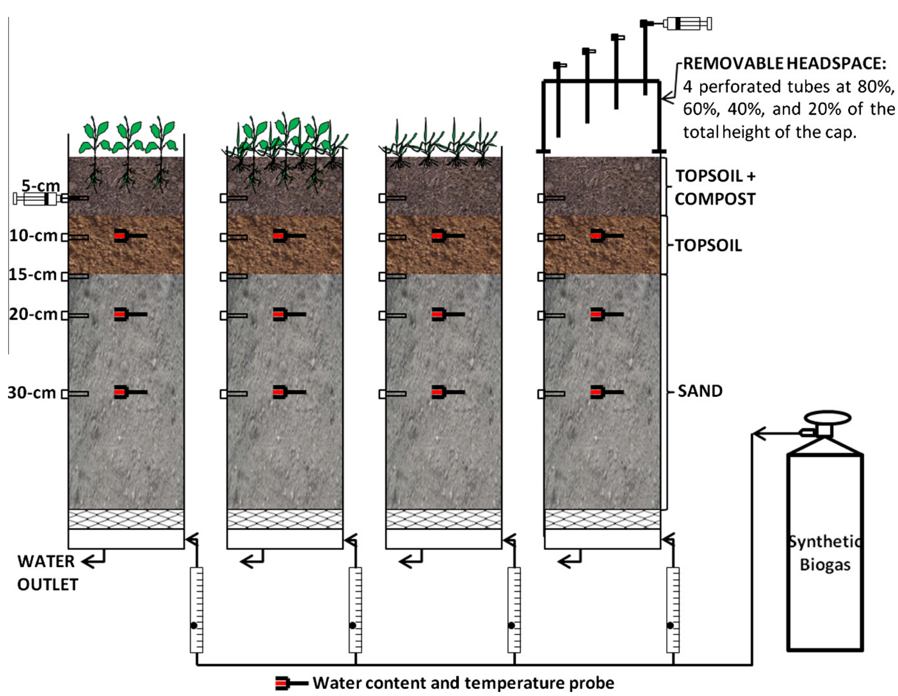

Fig. 1. Experimental design of laboratory columns.