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Effects of preconditioning the rhizosphere of different plant species on biotic methane oxidation kinetics

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ABSTRACT

The rhizosphere is known as the most active biogeochemical layer of the soil. Therefore, it could be a beneficial environment for biotic methane oxidation. The aim of this study was to document - by means of batch incubation tests - the kinetics of CH_4 oxidation in rhizosphere soils that were previously exposed to methane. Soils from three pre-exposure to CH_4 zones were sampled: the never-before pre-exposed (NEX), the moderately pre-exposed (MEX) and the very pre-exposed (VEX). For each pre-exposure zone, the rhizosphere of several plant species was collected, pre-incubated, placed in glass vials and submitted to CH_4 concentrations varying from 0.5% to 10%. The time to the beginning of CH_4 consumption and the CH_4 oxidation rate were recorded. The results showed that the fastest CH_4 consumption occurred for the very pre-exposed rhizosphere. Specifically, a statistically significant difference in CH_4 oxidation half-life was found between the rhizosphere of the VEX vegetated with a mixture of different plants and the NEX vegetated with ryegrass. This difference was attributed to the combined effect of the preconditioning level and plant species as well as to the organic matter content. Regardless of the preconditioning level, the oxidation rate values obtained in this study were comparable to those reported in the reviewed literature for mature compost.

1. Introduction

Biotic methane oxidation, a highly efficient biogeochemical process to reduce CH_4 emissions from landfills, can be optimized through the use of engineered biosystems. The latter term refers to biofilters, biowindows, and includes passive methane oxidation biocovers (PMOB). PMOBs are typically made up of a sequence of soil layers that promote the development of methanotrophs, a group of bacteria that use CH_4 as a carbon and energy source (Hanson and Hanson, 1996).

Although CH_4 oxidation has been extensively documented, there are a limited number of studies on the effects of vegetation on methanotrophic activity and CH_4 oxidation efficiency in landfills. Among these studies, Bohn et al. (2011) and Reichenauer et al. (2011) assessed the impact of several types of plant covers on CH_4 oxidation. Their studies concluded that CH_4 oxidation efficiencies of the tested passive biosystems differed, and that vegetation enhanced biotic CH_4 oxidation. Wang et al. (2008) evaluated how *Chenopodium album* L. affected methanotrophic activity. They observed a significant increase in the total number of soil culturable bacteria in soils seeded with *C. album* L. and exposed to landfill gas. According to Wang et al. (2008), the total number of methanotrophic bacteria in the seeded soils exposed to landfill gas was significantly higher than in soils either not exposed to landfill gas or seeded. In a recent study, Ndanga et al. (2013, 2015) reported the impact of *Trifolium repens* L., *Phleum pratense* L., and a mixture of both on aerobic CH_4 oxidation. They performed column studies (a 30-cm layer of sand topped with a 7.5-cm layer of top soil and a 7.5-cm layer of top soil enriched with compost) in the laboratory and in the field, and concluded that the influence of vegetation on CH_4 oxidation was not noticeable for CH_4 loadings up to approximately 100 $g\,m^{-2}\,d^{-1}$, which can be considered a high emission rate. In fact, Ndanga et al. (2013, 2015) observed that the bare soil performed as well as the 3 vegetated covers they analyzed. In all the above-mentioned studies, it was hypothesized that a positive impact of vegetation on biotic CH_4 oxidation could be attributed to the improvement of oxygen diffusion and to the enhancement of the nutrient supply through the root system.

The effect of vegetation on CH_4 oxidation in landfills may also be assessed through the efficiency of the rhizosphere soil in oxidizing CH_4. This is another subject that remains poorly documented in the technical literature relating to PMOBs incorporated in landfill

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final covers. The rhizosphere is the zone of contact between roots and soil that supports high levels of bacterial activity. Through root exudations (rhizodeposition), plants release organic compounds such as amino acids and sugars, which serve as energy substrates for soil heterotrophic microorganisms. This, in turn, may stimulate soil nutrient turnover with positive effects on methanotrophic populations. According to Katznelson (1946) and Atlas and Bartha (1993), the abundance of micro-organisms in the rhizosphere is generally 5–20 times greater than that found in non-vegetated soil. Therefore a well-developed rhizosphere soil might represent an environment conducive to methanotrophic growth and CH_4 oxidation.

However, studies of the effect of landfill gas on plant growth showed detrimental effects on plants in landfill. High CH_4 and CO_2 concentrations were found unfavorable to plant growth, affecting root development and rhizospheric activity (Chan et al., 1991, 1997; Nagendran et al., 2006). The variability in microbial composition and activity in the rhizosphere generally depends on the quality and quantity of root exudations, which vary according to root development, plant species, age and vigor, as well as site specific factors such as soil chemical properties and climatic conditions (Walton et al., 1994).

The aim of this study was to assess the importance of the rhizosphere in CH_4 oxidation kinetics for a limited number of plant species commonly found at the Saint-Nicephore landfill in Quebec, Canada. We hypothesized that preconditioning the rhizosphere soils (therefore the microflora) of final cover systems (including biocovers) by exposing them to CH_4 might lead to faster and earlier CH_4 oxidation, in comparison with unconditioned rhizosphere soils. This subject has been previously documented in the literature for other environments such as wetlands, rice paddies and forest soils (van der Nat and Middelburg, 1998; Popp et al., 2000; Van Bodegom et al., 2001; Ding et al., 2004; Lee et al., 2011). These studies revealed that CH_4 removal by biotic oxidation in rhizospheres varies widely, depending on soil type, plant species, seasons etc. However, the study presented herein is the first to document CH_4 oxidation kinetics of preconditioned rhizosphere soils in landfill covers.

An experimental plan was designed to document CH_4 oxidation of rhizosphere soils associated with 3 levels of pre-exposure and different plant species. The kinetic approach, which has been commonly employed to assess the capacity of soil materials to oxidize CH_4, was adopted herein. It involves batch incubation for determining the kinetic parameters, such as the CH_4 oxidation rate and its associated half-life ($t_{1/2}$).

One practical outcome of this investigation was the possibility to assess whether or not some level of pre-exposure of the rhizosphere soil to methane, prior to construction of the biosystem, for example, might result in a faster - and more substantial - reduction in fugitive methane fluxes from landfills.

2. Materials and methods

2.1. Study site

Samples were obtained from a landfill site located in the municipality of Drummondville, Quebec, Canada. Sampling regions were chosen based on plant cover and CH_4 pre-exposure level. Three CH_4 pre-exposure zones were selected: (1) never-before pre-exposed zone (NEX), located >30 m away from the landfill site, where the plant species found on the natural soil were the same as on the covered parts of the landfill (visual inspection); (2) moderately pre-exposed zone (MEX), located in an area where the final cover was placed approximately 8 years ago, and where surface CH_4 concentrations oscillate between 0 and 200 ppm; (3) very pre-exposed zone (VEX). The latter was not actually a zone, but our own field column experiments, which, as described by Ndanga et al. (2015) were exposed to high CH_4 loadings (>180 g CH_4 m^{-2} d^{-1}, as measured by flow meters). The soil used as cover soil for the landfill or in field columns was the natural soil on the landfill site. CH_4 concentrations were measured using a Flame ionization detector (TVA-1000B, Thermo Scientific).

For each CH_4 pre-exposure zone, different plant species were considered for the study: clover (CL, *Trifolium* spp. L.), timothy grass (TG, *P. pratense* L.) and perennial ryegrass (RG, *Lolium perenne* L.). These species are commonly found in the area within and around the landfill. However, for the VEX soil, instead of ryegrass, the rhizosphere soil of a mixture (Mix) of clover and timothy grass was sampled. A framework of the kinetic study is presented in Fig. 1. Nine treatments were considered, each treatment representing a combination of CH_4 pre-exposure level and plant species. All 9 treatments were replicated 5 times, each representing a testing block.

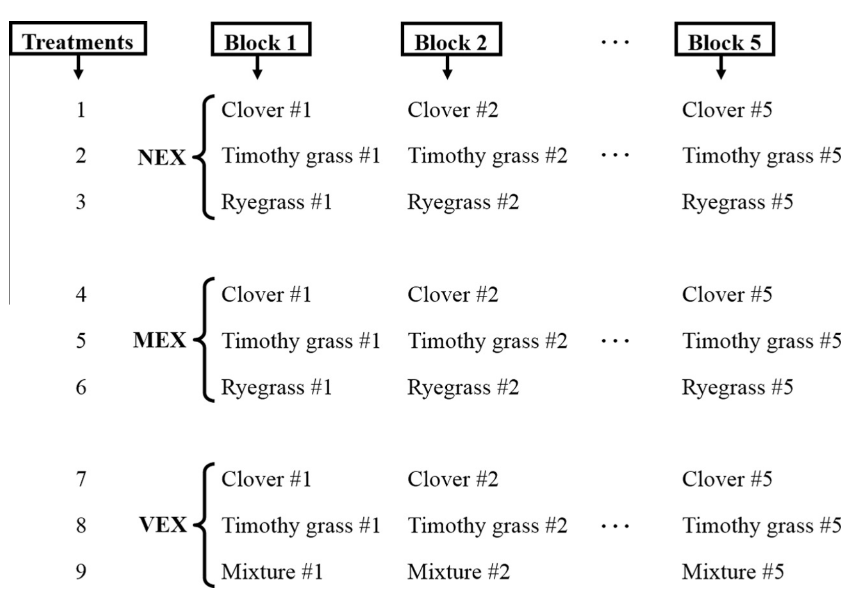

Fig. 1. Schematic summary of the CH_4 oxidation kinetic analyses.