An Analysis of the Effects of Vegetation on CH_4 Emission in Landfill Cover Soils: Combined Effects of Root Architectures, Radial Oxygen loss, Root-water Uptake and Plant-Mediated CH_4 Transport

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Introduction

Biologically active cover soil is a crucial technology and practice in controlling fugitive CH_4 emitting to the atmosphere in landfills. The surface of the cover soil will be covered with native plants when the landfill is closed.

Few models have been built to model the effect of vegetation on CH_4 transportation, oxidation and emission in landfill cover soil. The objective of this study is to use numerical modelling technique to provide new insights into the coupled effects of vegetation on CH_4 transportation oxidation and emission. A series of parametric studies were also studied to identify critical factors that affect CH_4 oxidation efficiency, including moisture water content, cover soil temperature, root architectures (triangular, parabolic, exponential, uniform and circular), ROL rate, transpiration rate and root depth. The results obtained will help to improve the understanding of CH_4 emissions in vegetated landfill sites and mitigation of CH_4 gas emission via selecting appropriate plant species in landfill cover soils.

Method

A 1D numerical simulation was conducted following the identical boundary conditions (as shown in Fig. 1). LFG with 50% CH_4 (v/v) and 50% CO_2 (v/v) with a constant flux flow into the cover soil from the bottom boundary. In the upper boundary, four gases, CH_4, CO_2, O_2 and N_2 are only considered. The volume fraction of CH_4, CO_2, and O_2 were set as the same in the air, and the remaining is N_2.

The 1D numerical simulation with a height of 0.6 m as intermediate cover soil is built. The root surface areas for different root architectures are viewed as equal for fair comparison. Root depth, ROL rate and transpiration rate ranges from 0.05 to 0.55 m, 0 to 1.0×10^{-3} mol/m²·s and 0 to 8 mm/d for the parametric study. Transient analysis was conducted by simulating a continuous supply of LFG at the bottom of the cover soil for 30 days, while allowing the plant in the cover soil surface to transpire under a constant rate.

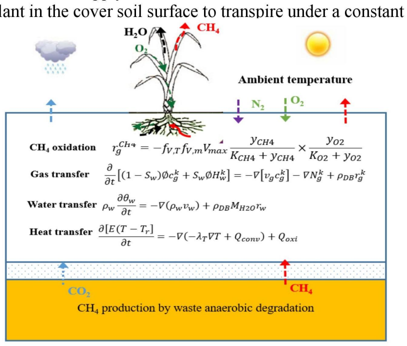

Fig. 1 The basic structure of the simulation model

Results and discussion

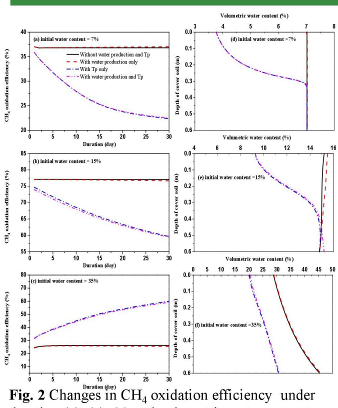

Fig. 2 Changes in CH_4 oxidation efficiency under duration (a), (c), (e) and volumetric water content distributions in cover soil profiles (b),(d) and (f) under different initial water contents. Tp = 2 mm/d, root depth = 0.3m with parabolic root architecture.

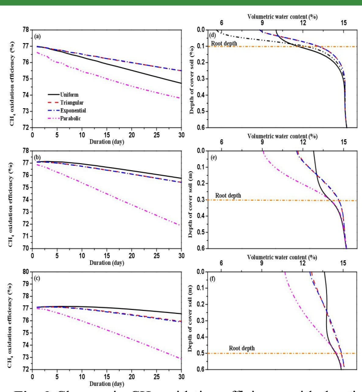

Fig. 3 Changes in CH_4 oxidation efficiency with duration (a), (c)and (e) and volumetric water content distribution in the cover soil profile(b),(d) and (f) under different root depths for different root architectures. Tp = 2 mm/d, initial water content = 15%.

- The effect of plant transpiration on CH_4 oxidation is mainly determined by the initial water content;
- 10% more CH_4 was emitted into the atmosphere in plant-covered areas than bare areas in dry conditions (7% and 15% water content);
- CH_4 oxidation was improved by 23% in initial wet conditions(35% water content);
- 10% more CH_4 was oxidized in roots with parabolic architecture than other root architectures when initial water content was 35%.

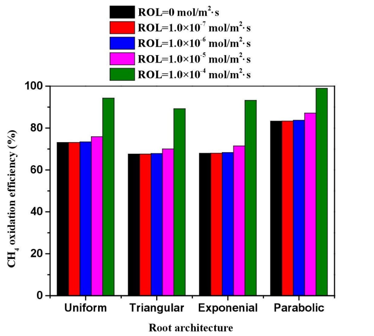

Fig. 4 Average CH_4 oxidation efficiencies during the 30 day study period under different ROL rates for different root architectures. Tp= 2 mm/d, root depth = 0.3 m and initial water content = 35%.

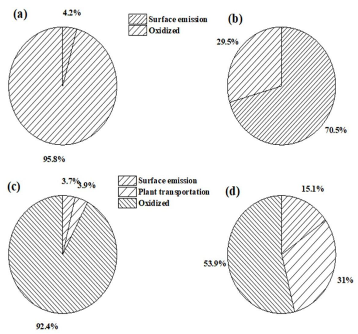

Fig. 5 The fate of CH_4 in the cover soil: (a) bare areas, initial water content =15%, (b) bare areas, initial water content=35% (c) vegetation areas, initial water content =15% and (d) vegetation areas, initial water content=35%.Tp=2mm/d, root depth=0.3m, ROL=1.0×10^{-5}mol/m²·s, parabolic root architecture.

- CH_4 oxidation efficiency was greatly improved when ROL rate increased to 1.0×10^{-5} mol/m²·s;
- The CH_4 oxidation efficiency for different root architectures follow the orders: parabolic>uniform>exponential> triangular
- When initial water content was 15%, 51.4% was directly emitted due to plant transportation, and only 48.6% was emitted from the surface of the cover soil. However, when intial water content is 35%, CH_4 emission from plant was 2 times higher than from cover soil surface.

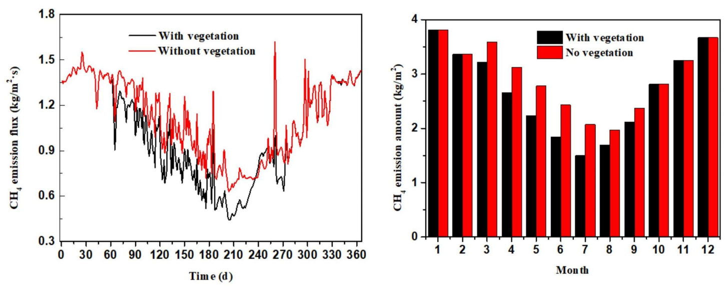

Fig. 6 Yearly CH_4 emission predication from landfill cover soil

- The yearly CH_4 emission from plant-covered areas was 32.2kg/m², and 35.2kg/m² in bare areas.
- The combined effects of plant is helpful to CH_4 mitigation.

Conclusion

This study proposes a newly improved theoretical model that couples the effect of plant (including root-water uptake, root-oxygen release and plant CH_4 transportation) and microbial CH_4 oxidation in landfill unsaturated soil. The CH_4 oxidation efficiency for roots with parabolic architecture is sensitive to the initial water content. When the initial water content is 15%, plants with parabolic root architectures has the lowest CH_4 oxidation efficiency, while the CH_4 oxidation efficiency is the highest when the initial water content is 35%. The aeration conditions and water shortage caused by plant transpiration is the dominant mechanism for CH_4 oxidation. The CH_4 oxidation is significantly enhanced when the root-oxygen release rate is higher than 1.0×10^{-4}mol/m². Plants are the main pathway for CH_4 release, and more than 31% of input CH_4 emitted to the atmosphere from plants directly when the initial water content is 35%.

The model is based on an interactive mechanism of cover soil and vegetation to provide the reliable method for greenhouse effect estimation of landfill CH_4, which play a theoretical and practical significance on the landfill CH_4 control and reuse. However, this model is only a theoretical model that more comprehensive field and laboratory dataset is needed to validate the model. Further, more comprehensive study including the weather conditions (i.e. rain, air temperature, evaporation) and plant growth should be taken into account to build a process-based model which can predict the daily and yearly CH_4 emission amount.