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Microbial fuel cell as mitigation strategy for methane emissions from paddy field

Anacleto Rizzo, Fulvio Boano, Roberto Revelli, and Luca Ridolfi
Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Turin, Italy. Italy
(anacleto.rizzo@polito.it, fulvio.boano@polito.it, roberto.revelli@polito.it, luca.ridolfi@polito.it)

Microbial fuel cells (MFCs) are bioelectrochemical systems able to generate electricity from wetland soils, including paddies, exploiting the microbial decomposition of organic matter. A MFC is composed of an anode buried in the anaerobic submerged soil linked to a cathode placed on the top of the soil in the aerobic ponding water. A biofilm develops on the anode, where bacteria release electrons, oxidizing dissolved organic carbon (DOC) and using oxygen available at the cathode as electron acceptor. MFC technology is now in an early development stage and the efficiency in electricity production is still low. However, MFC can also be applied for secondary aims, among which one of great interest is the reduction of methane (CH_4) emissions from paddy fields. Indeed, DOC oxidation at the anode can be seen as an additional DOC sink in paddy soil environment, limiting the DOC availability for methanogens. In this work, a process-based mathematical model is proposed for a preliminary investigation of the efficiency of MFCs in limiting CH_4 emissions. The model relies on a system of partial differential mass balance equations to describe the vertical dynamics of the chemical compounds leading to CH_4 production. Many physico-chemical processes and features characteristic of paddy soil are included: paddy soil stratigraphy; spatio-temporal variations of plant-root compartment; water and heat transport; SOC decomposition; heterotrophic reactions in both aerobic and anaerobic conditions; root radial oxygen loss; root solute uptake; DOC root exudation; plant-mediated, ebullition, and diffusion gas exchange pathways. MFC is modeled as a DOC sink term, following a zero-order kinetic where the current density is assumed constant for the whole growing season. Different values of current density are tested, in accordance with values reported in literature about efficiency reached in paddy soils. Our results show a reduction of CH_4 emissions up to -28.1%, -24.1%, and -26.5% of daily minimum, daily maximum and total over the whole growing season, respectively, confirming the potential validity of MFC as a novel CH_4 mitigation strategy. Moreover, it is shown that transport processes limit the mitigation of CH_4 emissions at high current density. Finally, in order to maximize the reduction of CH_4 emissions, simulation results suggest to place the anode in the middle portion of the superficial layer.