Dances with Microbes: Understanding Greenhouse Gas Emissions with Biogeochemical Models

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Abstract: Production of greenhouse gases (GHGs) has long been a company of the life on Earth since 4 billion years ago. Along with the co-existing evolutions of life and its environment, the primary microbes gained energy through a series of reductive-oxidative reactions including fermentation, nitrification, denitrification, and aerobic respiration, which produced methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), respectively. The emergence of modern civilization didn't alter the microbes very much. With their unique characters of large reactive surface, fast reproduction and horizontal gene transfer, the microbes have been surviving from the tremendous catastrophes that have occurred on this planet. In fact, the balance of GHGs on this planet still largely relies on the microbial activities although human beings have set a strong interference. Nowadays when we launch campaigns to mitigate GHG emissions, we may have to learn how to dance around with the microorganisms. Four hypotheses have been raised to incorporate the microbial functions into a modeling framework. The hypotheses are (1) CO_2, N_2O and CH_4 are products of reductive-oxidative (redox) reactions through electron exchange between the electron donors and acceptors though mediated by microbes; (2) Occurrence of the electron exchange is determined by the redox potential (Eh) of the environment; (3) When the suitable Eh is established, the functional group of bacteria will build up their full capacity within a short term due to their rapid reproduction and horizontal gene transfer; and (4) When the microbial capacity is built up, the reaction rate will be in turn controlled by the availability of the relevant nutrient substrates based on the Michaelis-Menten Equation. A process-based model, Denitrification-Decomposition or DNDC, was developed based on the hypotheses to track the microbe-driven turnover of soil carbon (C) and nitrogen (N) in terrestrial ecosystems. The model was tested by a number of researchers worldwide against measured GHG fluxes at site scale during the past two decades. This collective effort on DNDC's calibration and validation should have set a decent basis for applying the model at regional or global scale. The world is faced by challenges from both food production and environmental degradation. We hope the international efforts on biogeochemical modeling will continuously enhance the analytical tool for a sustainable agriculture.

Keywords: Microbes; GHG emissions; DNDC model