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A dual-porous, biophysical void structure model of soil for the understanding of the conditions causing nitrous oxide emission

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Nitrous oxide is the fourth most important greenhouse gas. It is 300 times more potent than carbon dioxide, and two-thirds of anthropogenic nitrous oxide is emitted by agricultural land. This presentation will begin with a brief overview of the laboratory measurements of nitrous oxide emission from carefully characterised soils, presented in more detail by Cardenas et al.. The measurements were made in a twelve-chamber, gas chromatographic apparatus at North Wyke Research (formerly IGER). The presentation will then continue with a description of a void network model of sufficient accuracy and authenticity that it can be used to explain and predict the nitrous oxide production, and the modelling of the biological, chemical and physical processes for the production of nitrous oxide within the constructed network. Finally, conclusions will be drawn from a comparison of the model results with experiment.

The void network model

Nitrous oxide is produced by microbial activity located in ‘hotspots’ within the microstructure of soil, and nutrients and gases flow or diffuse to and from these hotspots through the water or gas-filled macro-porosity. It is clear, therefore, that a network model to describe and explain nitrous oxide production must encompass the full size range of pore space active within the process, which covers 6 orders of magnitude, and must make realistic suppositions about the positional relationship of the hotspots relative to the soil macro-porosity. Previous experimental (Tsakiroglou, C. D. et al, European J.Soil Sci., 2008) and theoretical approaches to the modelling of soil void structure cannot generally meet these two requirements. We have therefore built on the success of the previous uni-porous model of soil (Matthews, G. P. et al, Wat.Resour.Res, 2010), and the concept of a critical percolation path, to develop a dual porous model (Laudone, G. M. et al, European J.Soil Sci., 2010) with the following features:

- A porous unit cell, with periodic boundary conditions, and with a critical percolation path with the correct percolation characteristics and void volume of the macro-porosity of the soil.
- A solid phase between the pores of the large unit cell, with the correct volume of the fraction of larger soil aggregates (larger 1 mm).
- All the remaining pores of the large unit cell, which are not part of the critical percolation path, filled with smaller unit cells, which account for the micro-porosity of the soil sample.

We describe the construction of a model that closely matches the following characteristics of a specific example of typical arable soil, taken from the Warren field of the Rothamsted experimental farm at Woburn, although the model can be used for a wide range of soils:
(i) macroporosity and microporosity as measured by the water retention curve,
(ii) the shape of the water retention characteristic under a wide range of tensions,
(iii) the soil texture, and
(iv) the extent of irreducible water content.

Process model

We will describe the insertion of Michaelis-Menten kinetics and Crank-Nicholson diffusion equations into the precisely scaled model, building on previous diffusion modelling (Laudone, G. M. et al, Chem.Eng.Sci., 2008).

Comparison with experiment

A comparison with experimental results sheds light on (i) the positional relationships of aerobic and anaerobic bacteria relative to the critical percolation path, (ii) the relationship between the critical percolation path and the preferential / critical flow path (Figure 4), (iii) the extent of ignorance about the reaction kinetics of some of the fundamental processes occurring, (iv) the soil conditions that cause nitrous oxide emission, and (v) the effect of soil compaction on the emission.

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