Geophysical Research Abstracts
Vol. 19, EGU2017-1576-1, 2017
EGU General Assembly 2017

Influence of soil structure on nutrient cycling using microfluidic techniques

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The rising of atmospheric CO_2 levels and its effects on global warming make it necessary to understand the elements that regulate such levels and furthermore try to slow down the CO_2 accumulation in the atmosphere. The exchange of carbon between soil and atmosphere plays a significant role in the atmospheric carbon budget. Soil organisms deposit organic compounds on and in soil aggregates, either as exudates or dead remains. Much of this dead organic material is quickly recycled, but a portion, however, will stay in the soil for long term. Evidence suggests that micro-scale biogeochemical interactions could play a highly significant role in degradation or persistence of organic matter in soils, thus, soil physical structure might play a decisive role in preventing accessibility of nutrients to microorganisms.

For studying effects of spatial microstructure on soil nutrient cycles, we have constructed artificial habitats for microbes that simulate soil structures. Microfluidic, so called Lab-on-a-chip technologies, are one of the tools used to achieve our purpose. Such micro-habitats consist of pillar structures of difference density and surface area, tunnels with increasing depth, and mazes of increasing complexity to simulate different stages of soil aggregation.

Using microscopy and analytical chemistry, we can follow the growth of microorganisms inoculated into the “soil chip” as well as the chemical degradation of organic matter compounds provided as nutrient source. In this way, we want to be able to predict how soil structure influences soil microbial activity leading to different effects on the carbon cycle.

Our first results of a chip inoculated with natural soil showed a succession of organisms colonizing channels leading to dead-end arenas, starting with a high presence of bacteria inside the chip during the first days. Fungal hyphae growth gradually inside the channels until it finally occupied the big majority of the spaces isolating bacteria which dramatically decreased in number. The structure inside the soil chip changes dynamically due to the creation of biofilms. Such changes alter the spatial distribution inside the chip gradually, to the point of getting significantly different from the original structures. Fungal hyphae, bacterial biofilms, and microbial necro mass accumulation where the components altering the chip structure. These findings suggest that a considerable part of the soil structure is microbial biomass.

Using Lab-on-a-chip techniques leads to the creation of a much more realistic soil and ecosystem model, resembling spatial and chemical complexity in real soil structures at a micrometer scale, the scale relevant for soil organisms.

Understanding small-scale processes in the soils is crucial to predict carbon and nutrient cycling, and to enable us to give recommendations for soil management in agriculture, horticulture and nature conservation. If parameterization of soil structure as a central determinant for carbon sequestration is possible, it will allow strong argumentation for management practices that conserve and foster soil structure, such as low-tillage, support of mycorrhizal fungi, and reduction of heavy machinery usage.