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Relevance of biological soil crusts in terrestrial nitrogen cycling and the impact of global change

Bettina Weber (1) and the Biocrust nitrogen cycling team

(1) Multiphase Chemistry Department, Max-Planck-Institute for Chemistry, Mainz, Germany (b.weber@mpic.de), (2) Departamento de Agronomia, Universidad de Almeria, Almería, Spain, (3) Department of Limnology and Ecotoxicology, Technische Hochschule Bingen, Bingen, Germany, (4) Key Laboratory of Geographic Information Sciences, Ministry of Education, School of Geographic Sciences, East China Normal University, Shanghai, China, (5) Department of Agriculture & Food Sciences, University of Applied Sciences, Neubrandenburg, Germany, (6) Department of Environmental Science and Analytical Chemistry (ACES), Stockholm University, Stockholm, Sweden, (7) Max Planck Institute for Biogeochemistry, Jena, Germany, (8) Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA, (9) Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand, (10) Senckenberg Biodiversity and Climate Research Centre, Frankfurt am Main, Germany, (11) Atmospheric Chemistry Department, Max Planck Institute for Chemistry, Mainz, Germany, (12) Institute of Earth Sciences, University of Heidelberg, Heidelberg, Germany, (13) Institute of Plant Sciences, University of Graz, Graz, Austria, (14) U.S. Geological Survey, Southwest Biological Science Center, Moab, Utah, USA, (15) Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA

In drylands, which currently cover ∼40% of the global terrestrial surface area, biological soil crusts (biocrusts) form a regular surface cover. Biocrusts comprise photoautotrophic compounds, which could be cyanobacteria, algae, lichens, or bryophytes, growing together with heterotrophic fungi, bacteria and archaea in varying proportions and stabilizing the uppermost millimeters of the soil. According to the dominating photoautotrophic compound, they are broadly characterized as cyanobacteria-, lichen- and bryophyte-dominated biocrusts, which also represent successional stages in drylands.

In a global modelling approach, we quantified that biocrusts fix ∼26 Tg of nitrogen per year, corresponding to ∼1/2 of the terrestrial biological N fixation according to the most current IPCC report. In follow-up studies, we aimed at identifying potential atmospheric sinks for N compounds released by biocrusts. Lab measurements of cyanobacteria, lichen, and bryophyte community samples collected on different continents revealed that they regularly emit nitrous oxide (N_2O) during wetting and drying events and ^{15}N tracer experiments suggested that N_2O formation occurred during denitrification. In an alternative approach, a global process-based vegetation model for lichens and bryophytes was used to analyze their global emissions of the greenhouse gas, revealing similar geographical emission patterns and magnitudes, thus corroborating these results. In a second approach, we investigated the emission of nitric oxide (NO) and nitrous acid (HONO) by biocrusts. Based on laboratory, field, and satellite measurement data, we obtained a best estimate of ∼1.7 Tg per year for the global emission of reactive nitrogen from biocrusts, probably being formed during nitrification. During this study, emission patterns of NO and HONO were characteristic, differing depending on biocrust type. In a molecular approach, where we conducted qPCR and high-throughput 16S rRNA gene and fungal internal transcribed spacer (ITS) region sequencing, similar biocrust type characteristics were observed. Bacterial 16S and fungal 18S rRNA gene copy numbers increased, fungi became more relevant, and microbial communities became more dominated by specialized bacteria towards later successional stages. All these data were based on current environmental conditions. However, according to field studies and environmental modeling (based on global change scenarios of the IPCC) biocrusts are expected to decrease by ∼25-40% within the next 65 years. The effects of the projected anthropogenic climate change and land use intensification on global nitrogen cycling are hard to predict, as they affect both the extent and the activity of biocrusts under altered environmental conditions.

Summarizing our results, we could show that biocrusts play a major role in nitrogen fixation as well as the release of N_2O, NO, and HONO. We observed that different biocrust types are characterized by unique emission patterns and microbial communities, suggesting that the dominating photoautotrophic organisms have an impact on habitat characteristics, facilitating microbial communities, which themselves influence the physiological functioning of biocrusts. Global change is expected to strongly affect global biocrust cover and composition, thus also influencing local and global nutrient cycles.