Substrate limitation to soil microorganisms in desert ecosystems: Carbon and nitrogen limitation in a High Arctic glacier foreland

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Arctic tundra is one of the desert ecosystems that are established in areas with extremely harsh environmental condition. A few studies conducted in the High Arctic have shown that microbial respiration rate and biomass are generally low in the early stages of succession. These findings suggest that some environmental factors limit soil microbial activity and growth in the early stages of succession.

In this study, we hypothesized that soil respiration in High Arctic glacier forelands is limited by low carbon and nitrogen availability and that key factors limiting microbes vary along the successional gradient. To test these hypotheses, we studied responses of microbial respiration to carbon and nitrogen amendments. Phospholipid fatty acid (PLFA) content, an index of microbial biomass and community structure, was also investigated.

This study was conducted at the front of East Brogger Glacier in Ny-Alesund, Svalbard. Sites E and L were set up as the early and late stage of succession, respectively. At Site E, the mineral soil of the 0-5 cm layer was sampled. At Site L, the organic soil layer (FH layer) and mineral soil of the 0-5 cm layer (under the FH layer) were collected.

We allocated four treatments; C+, the addition of glucose; N+, the addition of ammonium nitrate; CN+, the addition of both glucose and ammonium nitrate; and control. Soil respiration rates were measured using an open-flow system with an infrared gas analyzer. PLFA analysis was performed on the freeze-dried soil samples. The total content of PLFAs (TotPLFAs) and PLFA composition were used to indicate the total microbial biomass and the microbial community structure, respectively.

In Site E, addition of neither carbon (C+) nor nitrogen (N+) increased the microbial respiration rate significantly. In contrast, the respiration rates of soils with both carbon and nitrogen added (CN+) increased significantly. These results suggest that heterotrophic microbial activity in the early stage of primary succession in a High Arctic glacier foreland is limited by twin deficiencies of carbon and nitrogen. In the mineral and organic soils of Site L, addition of carbon alone (C+), as well as the addition of both carbon and nitrogen (CN+), stimulated the respiration rate despite the fact that the soil possessed substantial concentrations of total C. This fact suggests that the respiration rate was limited primarily by deficiency of a labile carbon substrate.

In contrast to the respiration rate, the TotPLFAs content, as an index of total microbial biomass, was not affected by the addition of carbon or nitrogen or both for any soils. The increase in respiration rates without the increase in microbial biomass indicates changes in physiological activities of microbial communities such as enzymatic activity. In this study, a small shift in microbial community structure was observed. For example, the proportion of unsaturated fatty acids in CN+ treatment was slightly increased after addition for all soil samples. This shift might also affect the respiration rate without increasing microbial biomass.

In conclusion, although the microbial respiration rate in the High Arctic glacier foreland was limited by carbon and nitrogen availability, the extent of that limitation differed among successional stages. Especially in the early stage of primary succession, low availabilities of both carbon and nitrogen were important limiting factors of the microbial respiration rate.

In this report, these results will be compared to those from other desert ecosystems where the microbial respiration rate, microbial biomass, and soil carbon and nitrogen contents are low and the substrate limitation in the early stages of ecosystem development will be discussed.