

永久凍土における有機物および養分循環の制御要因 Controls over turnover of organic matter and nutrients in permafrost soils

藤井 一至^{1*}; 松浦 陽次郎¹; 藤井 創一郎²; 稲垣 善之¹; 大澤 晃²

FUJII, Kazumichi^{1*}; MATSUURA, Yojiro¹; FUJII, Soichiro²; INAGAKI, Yoshiyuki¹; OSAWA, Akira²

¹ 森林総合研究所, ² 京都大学農学研究科

¹Forestry and Forest Products Research Institute, ²Graduate School of Agriculture, Kyoto University

Introduction: Plant productivity on permafrost soils is limited by nutrient supply from organic matter. Organic matter decomposition and nutrient release can be limited by cold climate, flooding, and recalcitrance of bryophytes (lichen and moss). Plant-soil association (white spruce on mineral soil, black spruce on organic soil, and shrub tundra on lowland soil) suggests the hypothesis that plant acquisition strategies for nutrient (esp., amino acids/inorganic N) can be matched by nutrient supply from soil organic matter. To test this, turnover of organic matter and nutrient release was investigated for three types of ecosystems in Northwest Territory, Canada; white spruce forest (WSF) on the upland soil derived from glaciofluvial sands, black spruce forest (BSF) and tundra (TND) in lower position on fluvial sediments.

Methods: We measured soil organic carbon (SOC) storage [organic and mineral soil layers (0 to 30 cm)], soil temperature and moisture, aeration index [Eh, free Fe oxides (oxalate-extractable Fe)] of soils, and the decomposition rates of litter (lichen, moss, and root litter) and cellulose filter paper buried in the soils. Regarding soil N dynamics, the concentrations of organic and inorganic N in soil solution (zero-tension lysimeter) were measured. Root uptake of dual-labeled (¹³C, ¹⁵N) glutamic acid, ¹⁵N-labeled ammonium, and ¹⁵N-labeled nitrate was measured 24 h after spike of mixture solution.

Water dynamics: Episodic flooding events were observed following spring snowmelt at all sites. Rapid snowmelt and water percolation enhanced aeration in the sandy soil profile of WSF, while the BSF and TND soils were saturated by water flooding on impermeable permafrost layer (30 cm deep) even in summer. The seasonal cycles of reducing- and oxidizing- conditions were recorded as accumulation of free Fe oxides in the soils.

C dynamics: The C stocks in the organic and mineral soil layers were greater in TND (188 Mg C ha⁻¹) and BSF (207-237 Mg C ha⁻¹) than in WSF (37 Mg C ha⁻¹). When the regression analysis was conducted for 15 soil profiles, there was a positive correlation between SOC storage and free Fe oxide concentration. The high concentrations of free Fe oxides in soils appeared to be an index of poor drainage and high SOC storage. Mass loss rates of cellulose filter paper, lichenous litter, and root litter followed the order: WSF>TND>BSF. Water flooding and cold climate retarded decomposition of organic matter in BSF and TND. The development of hummocky micro-topography, which was recorded as the tilting of drunken forest, resulted in accumulation of sparingly-decomposable lichen and moss debris in BSF. The warmer and aeration conditions in sandy upland soil of WSF enhanced turnover of organic matter.

N dynamics: Dissolved organic N is abundant in soil solution at all sites. Nitrogen species in soil solution was dominated by nitrate and ammonium ions in TND soil, while it was ammonium in WSF and BSF soils. Regarding N uptake by plants, TND plants (shrub birch and grasses) preferentially absorb inorganic N (ammonium and nitrate), while white spruce and black spruce could also utilize amino acid-N. Both C and N of amino acids were assimilated by white spruce roots, while only ammonium was transferred to roots of black spruce probably after rapid mineralization by mycorrhizae or roots. N preference of plants is consistent with the dominant N species in soil solution.

Conclusions: Water flooding as well as cold climate retarded turnover of organic matter in black spruce forest. Despite slow turnover of organic matter, black spruce can utilize amino acids as well as ammonium. In warmer and aerated sandy soil, white spruce can absorb both amino acids and inorganic N. In the lowland tundra soil rich in inorganic N, plants can absorb inorganic N. This highlights the importance of considering plant-soil association to predict responses of "sensitive" ecosystem to future changes in flooding, fires, and climate.

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