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Temporal Disconnect of Seasonal Plant Nutrient Demand and Thaw Depth implies an Increasing Source of N_2O in High-Latitude Permafrost Ecosystems

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Thawing and degradation of permafrost in high latitudes could have an important effect on the Earth's greenhouse budget. Implications of increased nutrient availability resulting from thawing of nutrient-rich permafrost, however, remain poorly assessed, despite nutrients having being identified as a strong present-day constraint for plant growth and microbial activity in the high latitudes. In our pan-arctic scale study, we extend the terrestrial ecosystem model QUINCY, which already couples C-N-P cycles in soil and vegetation, for a better representation of high-latitude processes. With this model version, we perform historical simulations at the site-level over 1960-2019. Averaged over high-latitude grassland sites, our simulations show an average increase in the soil active layer depth of 0.1m and an increased gradient of biologically-available P and N at the permafrost front. In spite of this, only 11 % of the simulated increase over the GPP (+34%) is a result of increased nutrient supply from permafrost organic matter degradation. This owes to spatial and temporal decoupling of the simulated vegetation growth peak (mid-to-late-July), the time period where plant nutrient demand is the highest, and the maximum of the seasonal thaw depth (mid-to-late August), the time period in which nutrients in the deep active layer would potentially be available for uptake. As a result, increased nitrogen at the permafrost front and alternating aerobic-anaerobic conditions contribute to enhancing nitrification and denitrification in the model, causing a weak source of N_2O to the atmosphere of 0.7 kg N ha^{-1} yr^{-1}, which undergoes a considerable upward trend of up to 0.1 kg N ha^{-1} $decade^{-1}$, locally,over the simulation time frame. Considering the vastness of the permafrost domain, and that N_2O emissions from these regions have been largely neglected in the past, these results imply that high latitudes could be a considerable and growing contributor to the global atmospheric N_2O budget.