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Land carbon cycle projections for the 21st century with a model of combined carbon, nitrogen and phosphorus cycling

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Terrestrial carbon (C) cycle models applied for climate projections simulate a strong increase in net primary productivity (NPP) due to elevated atmospheric CO_2 concentration during the 21st century. These models usually neglect the limited availability of nitrogen (N) and phosphorus (P), nutrients that commonly limit plant growth and soil carbon turnover. To investigate how the projected C sequestration is altered when stoichiometric constraints on C cycling are considered, we incorporated a P cycle into the land surface model JSBACH, which already includes representations of coupled C and N cycles.

The model reveals a distinct geographic pattern of P and N limitation. Under the SRES A1B scenario, the accumulated land C uptake between 1860 and 2100 is 13% (particularly at high latitudes) and 16% (particularly at low latitudes) lower in simulations with N and P cycling, respectively, than in simulations without nutrient cycles. The combined effect of both nutrients reduces land C uptake by 25% compared to simulations without N or P cycling. However, the quantification of P limitation remains challenging as the poorly constrained processes of soil P sorption and biochemical mineralization strongly influence the strength of P limitation. After 2100, increased temperatures (+5 K) and high CO_2 (700 ppm) concentrations cause a shift from N to P limitation at high latitudes, while nutrient limitation in the tropics declines. The increase in P limitation at high-latitudes is induced by a strong increase in NPP and the low P sorption capacity of soils, while a decline in tropical NPP due to high autotrophic respiration rates alleviates N and P limitation. These findings indicate that global land C uptake in the 21st century is likely overestimated in models that neglect P and N limitation. In the long-term, insufficient P availability might become an important constraint on C cycling at high latitudes. Accordingly, we argue that the P cycle must be included in global models used for C cycle projections.