Phosphorus limitation reduces carbon sink in the future

Dr. Daniel Goll, a scientist in the department „The Land in the Earth System" at the Max Planck Institute for Meteorology (MPI-M), has published the first study with a comprehensive Earth System Model that accounts for phosphorus and nitrogen nutrient limitation on future uptake of CO_2 by the terrestrial biosphere. Dr. Goll demonstrated that neglecting the limited availability of phosphorus and nitrogen for the land ecosystems leads to overestimation of plant growth and soil carbon turnover in Earth System Models. Therefore, models that do not consider these nutrients overestimate the terrestrial carbon sink and underestimate future atmospheric CO_2 concentrations.

Climate models used for future projections, including the current Earth System Model of MPI-M (MPI-ESM), usually incorporate a carbon (C) cycle. These models simulate a significant increase in plant productivity in response to the elevated atmospheric CO_2 concentration in the 21st century. With a few exceptions, these models do not account for the limited availability of both nitrogen (N) and phosphorus (P) on land. Since plant growth and the turnover of C can be limited by the lack of P and N, this approach is problematic.

In his dissertation, Daniel Goll has incorporated a phosphorus cycle into the land surface model JSBACH (**J**ena **S**cheme for **B**iosphere-**A**tmosphere **C**oupling in **H**amburg), which already includes a nitrogen cycle. The biogeochemical module in JSBACH calculates plant growth, the decomposition of plant matter and the redistribution of nutrients in the soil. Daniel Goll has studied how P and N affect plant growth and turnover of C in the soil, by calculating the cycles of C, N and P with JSBACH with boundary conditions from simulations of the global MPI-ESM (SRES A1B scenario).

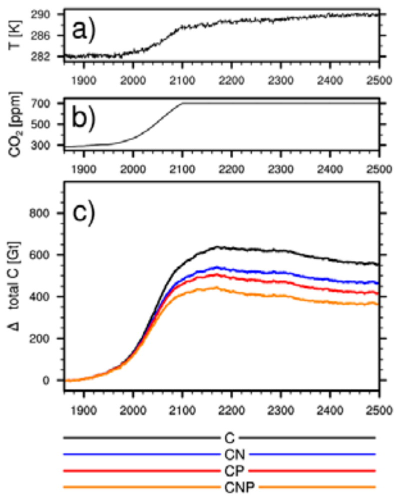

Figure 1: Simulated change in land carbon storage under the SRES A1B scenario. Shown are the 10-yr mean of soil temperature (a), the CO_2 concentration as used in the forcing simulation (b), and the resulting change in total land C storage (c). C – only carbon, no nutrients considered; CN - nitrogen considered; CP – phosphorus considered; CNP – phosphorus and nitrogen considered.

The model results show indeed a significant effect of nutrient availability: the accumulated land C uptake for the period 1860 – 2100 is by 13% (due to limitation by nitrogen) and 16% (due to limitation by phosphorus) lower than in simulations without the nutrient cycles of N and P, respectively. If both, the N and P cycles, are taken into account in JSBACH, the future land C uptake is reduced by 25%. P and N limitations are equally important, and they are to a large degree additive (figure 1). This additive effect can be traced back to the remarkable differences in the geographical pattern of P and N limitations. While N limitation mainly reduces the uptake in high latitudes, the availability of P mainly affects lower latitudes (figure 2, resp. animation).

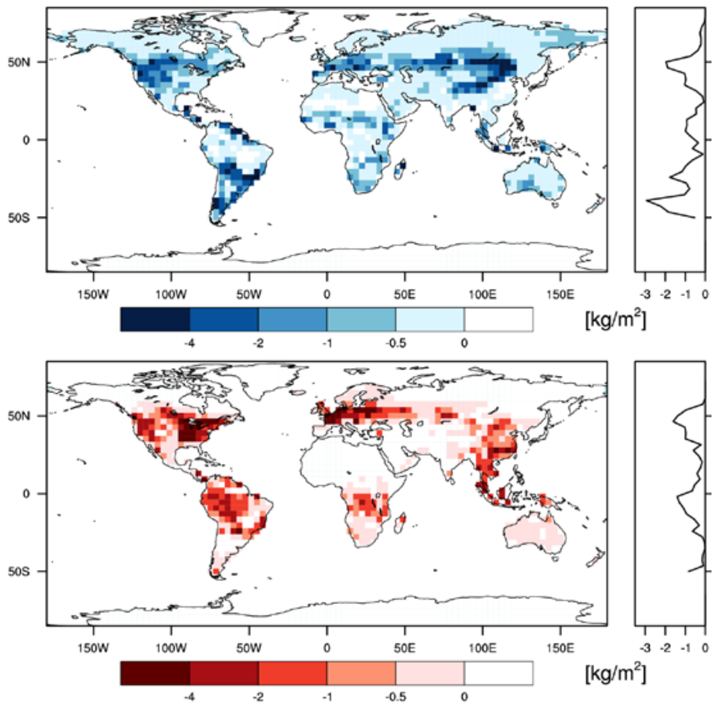

Figure 2: The reduction in C storage (kg m^{-2}) by nutrient limitation at the end of the 21st century. Shown is the difference in the mean C storage (2070-2099) between the CN simulation and the C-only simulation (upper panel), and between the CP simulation and the C-only simulation (lower panel). The latitudinal means over land points are shown on the right side.

Why do these geographical differences exist? The answer lies within the age of soils. Young soils typically contain more P than N, as the later is taken from the atmosphere gradually by biological fixation. In contrast, P accumulates by weathering of the parent rock. As soils age, the parental material becomes P-depleted and P gets progressively occluded in secondary minerals which are unavailable for plants. Therefore, old, highly weathered soils tend to have low P availability. As glaciation has reset soil formation at high latitudes, these soils tend to be much younger than the ones at low latitudes, where glaciation was absent for hundreds of millions of years. Additional mechanisms, such as leaching and volatilization, may also cause the occurrence of nutrient limitation on timescales of years to centuries.

After 2100, the simulations with continuously rising temperatures but a constant CO_2 concentration (Fig. 1 a, b) show that P rather than N limits the carbon uptake in high latitudes. This finding is novel and counterintuitive, since a common view is that P limitation plays a role mainly in the tropics. However, the quantification of the P cycle remains challenging because of limited experimental data. To constrain the P availability, better and larger datasets as well as observational networks are needed.

Conclusion: Models that do not account for N and P limitation clearly overestimate the land C uptake during the 21st century and underestimate future atmospheric CO_2 concentrations. In the long term, insufficient P availability might become an important constraint on C cycling at high latitudes. Accordingly, it is necessary to include the P cycle in models to make future projections more plausible.

Paper:

Goll, D. S., Brovkin, V., Parida, B. R., Reick, C. H., Kattge, J., Reich, P. B., van Bodegom, P. M., & Niinemets, Ü (2012).: Nutrient limitation reduces land carbon uptake in simulations with a model of combined carbon, nitrogen and phosphorus cycling, /Biogeosciences/, 9, 3547-3569. doi:10.5194/bg-9-3547-2012. PDF

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