The exchange of inorganic phosphorus between soil solution and matrix might largely affect the model predictions of terrestrial carbon cycle

Lin Yu\(^1\), Bernhard Ahrens\(^1\), Thomas Wutzler\(^1\), Marion Schrumpf\(^1,2\), Julian Helfenstein\(^3\), Chiara Pistocchi\(^4\), and Sönke Zaehle\(^1,2\)

\(^1\)Max Planck Institute for Biogeochemistry, BGI, Jena, Germany
\(^2\)International Max Planck Research School (IMPRS) for Global Biogeochemical Cycles, Jena, Germany
\(^3\)Group of Plant Nutrition, ETH Zurich, Lindau, Switzerland
\(^4\)Montpellier SupAgro-CIRAD-INRA-IRD, Montpellier, France

Phosphorus (P) availability may influence the response of terrestrial ecosystems to environmental and climate change. Soil biogeochemical (organic) and geophysical (inorganic) P cycling processes are the key players in this regulation. There has been a continuous effort to include P cycling processes into terrestrial biosphere models (TBMs) and many modelling studies agreed on the significance of organic P cycling processes to terrestrial ecosystems. However, the role of inorganic P cycling processes remains unclear. Although the model representations of inorganic P cycling in most TBMs are similar, their parameterisations differ greatly, and none of TBMs have been validated against soil P measurements.

In this study, we developed a new algorithm based on the two-surface Langmuir isotherm to describe the inorganic P exchange between soil solution and soil matrix in the QUINCY TBM, and tested both the novel and conventional models at five beech forest sites in Germany along a soil P stock gradient, which are the main study sites of the German Research Foundation (DFG) funded priority programme 1685.

We conducted a literature review on Langmuir P sorption parameters, which indicates that the P sorption capacity \(S_{\text{max}}\) is strongly correlated with soil texture and the Langmuir coefficient \(k_m\) is strongly correlated with soil pH and organic matter (OM) content. We divided soil P sorption sites into the OM-rich clay and silty sites and OM-poor sandy sites and extracted empirical equations to calculate their \(S_{\text{max}}\) and \(k_m\).

The two-surface Langmuir isotherm approach was implemented to QUINCY, and both the novel and conventional (one-surface Langmuir isotherm) models were applied to the study sites. The models were evaluated with observed soil inorganic P fractionations, foliar N and P contents, and normalized vegetation carbon (C) without calibration. The novel model significantly improved the goodness of model fit to P fractionation measurements at all sites. Both models were able to adequately capture the observed foliar N and P contents, but only the novel one reproduced the
observed pattern of vegetation C along the soil P gradient.

We further tested the effect of both models on the responses to CO$_2$ addition, P addition and C&P addition at all study sites. The conventional model showed stronger ecosystem responses to P and C&P additions than the two-surface Langmuir one, especially at P-poor sites. It is probably due to that plants store more added P in the conventional model than the novel one. We also tested the sensitivity of both models to the P cycling parameterisation at one low-P site. Despite better model fit to the observed soil P fractionation, the novel model also produced higher and more robust gross primary production, foliar P content and vegetation C than the conventional one.

In summary, we showed that the two-surface Langmuir isotherm approach adequately reproduced the observed soil P fractionations and the pattern of vegetation C along a soil P gradient, owing to its better representation of inorganic P cycling and thus C-P interactions, particularly at low-P ecosystems.