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Dynamic leaf nitrogen and phosphorus under increasing nutrient co-limitation in a land surface model

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Leaf nutrient contents, in particular nitrogen (N) and phosphorus (P), are key plant traits, linking to processes such as photosynthesis and respiration. Traditionally, plant traits are considered to be constant in time, but there is ample observational evidence that nutrient content varies with changes in environmental conditions. Specifically, increased atmospheric CO_2 drives increased plant growth and potentially increases in plant nutrient limitation, while anthropogenic N deposition further drives an imbalance in the N and P available to plants. Therefore, being able to dynamically, and accurately, represent leaf N and P content in land surface models (LSMs) is critical to predicting future ecosystem response to global change.

Most LSMs that include dynamic leaf N and P do so through a set of empirical functions that balance out demand and supply of nutrients. However, such representations do not take into account the differing physiological roles of the two nutrients, with N being directly linked to photosynthetic compounds, while P has a much stronger control on new biomass growth and respiration.

Using the QUINCY land surface model we represent physiologically-realistic dynamic leaf N and P content, using optimality theory, which assumes that plants alter their structure and function in order to maximize growth. We test the model using data from ICP Forests, a spatially extensive European network of sites with repeated, standardized measurements of leaf N and P content covering the period 1990 - present. We show that the new model representation performs better than the standard empirical functions, both in terms of spatial distribution of leaf nutrient content and its change through time, being able to reproduce the observed shift towards P limitation caused by increased N deposition. Most importantly, the model does not rely on the law of the minimum principle, being able to represent true co-limitation and allow leaf N and P to vary with different physiological and environmental pressures, thus creating more robust and realistic predictions.