**Impacts of nitrogen and phosphorus co-limitation on global carbon cycling**

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**Abstract**

Soil Nitrogen (N) and Phosphorus (P) availability strongly modulate the terrestrial ecosystem carbon cycle, including how plants respond to elevated atmospheric CO2 concentrations. Plant growth and ecosystem carbon accumulation depend on plant strategies of nutrient uptake and biomass accumulation under the uneven stress of N versus P availability. Acknowledging the importance of N and P limitations, two fundamental concepts have been widely supported in the literature: Liebig’s Law of the Minimum (LLM) and the Multiple Limitation Hypothesis (MLH). For example, applying LLM, a more limited supply of ecosystem P in the future compared with N will dramatically dampen the rate of ecosystem carbon accumulation. Conversely, based on MLH, terrestrial plants possess multiple pathways to overcome the uneven N and P co-limitation and achieve reasonably high growth, through adjusting photosynthesis rates based on leaf N and P concentrations, investing resources to enhance phosphatese or nirogenase activity, and so on. We implemented these two contrasting co-limitation laws in the Energy Exascale Earth System Model (E3SM) land model (ELM) and find that MLH better captures observed plant responses to different nutrient perturbations (*n* = 98), while LLM fails to capture how nitrogen and phosphorus limited systems respond to phosphorus and nitrogen fertilization, respectively. More importantly, LLM and MLH diverge dramatically in simulating the future responses of plant growth and ecosystem carbon accumulation to elevated CO2 and lead to large ecosystem carbon stock differences. This analysis provides quantitative evidence on how co-limitation laws could affect understanding and prediction of the future carbon cycle.