**Global response patterns of plant functional traits to combined nitrogen and phosphorus addition are driven by additive individual effects of N and P addition**

Evan A. Perkowski1, Keith J. Bloomfield2, Hugo J. de Boer3, Alissar Cheaib1, Ning Dong4, Sandy P. Harrison5, Monika R. Kelley1, Jan Lankhorst3, Astrid Odé3, I. Colin Prentice2, Daniil J. Scheifes3, Benjamin D. Stocker6, Karin T. Rebel3, Huiying Xu7, Nicholas G. Smith1

The availability of nutrients such as nitrogen and phosphorus plays a key role in shaping plant ecophysiological responses to global change. While nitrogen availability is well-documented as a driver of leaf and whole-plant physiological responses to global change, the role of phosphorus– both individually and in interaction with nitrogen– in dictating these responses remains less understood. This knowledge gap arises in part due to a lack of a mechanistic framework for understanding how phosphorus availability influences traits related to photosynthesis, resource allocation, biomass partitioning, and growth. To assess the individual and interactive effects of nitrogen and phosphorus availability on leaf and whole-plant traits, we compiled a dataset from nitrogen and phosphorus addition experiments and conducted a global meta-analysis. We used this approach to examine general effects of nitrogen, phosphorus, and the combination of nitrogen and phosphorus addition on leaf and whole-plant physiological traits, quantifying the impact of these nutrient additions on net photosynthesis, photosynthetic capacity, leaf nutrient content, plant biomass accumulation, and biomass partitioning. We also investigated whether the effects of combined nitrogen and phosphorus addition were the product of additive, synergistic, or antagonistic individual effects of nitrogen and phosphorus addition.

Across experiments, nitrogen addition generally increased leaf nitrogen content on both a mass- and area-basis but did not change leaf phosphorus content, leading to an increase in the leaf nitrogen-to-phosphorus ratio. In contrast, phosphorus addition increased leaf phosphorus on a mass- and area-basis but did not change leaf nitrogen content, leading to a decrease in the leaf nitrogen-to-phosphorus ratio. We found no evidence to suggest that nitrogen or phosphorus addition influenced net photosynthesis or apparent photosynthetic capacity. Both nitrogen and phosphorus addition each increased aboveground biomass and did not alter belowground biomass, leading to a reduction in the root mass fraction and root-to-shoot ratio. The combined effects of nitrogen and phosphorus addition on leaf and whole-plant traits were generally the result of independent effects of each nutrient addition, indicating that the effects of combined nitrogen and phosphorus addition were the product of additive individual effects of nitrogen and phosphorus addition. These findings provide novel insights into how nutrient interactions shape plant trait variation and could be a useful tool used to develop a mechanistic framework for predicting the effects of phosphorus availability on plant trait responses to global change.