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

**Abstract**

The availability of nutrients such as nitrogen (N) and phosphorus (P) play an important role in shaping plant ecophysiological responses to global change. While nitrogen availability has been well-documented as a key driver of plant responses to global change, the role of phosphorus – both individually and in combination with nitrogen – remains less understood. This knowledge gap arises in part due to a lack of a mechanistic framework for understanding how P availability influences traits related to photosynthesis, resource use, biomass partitioning, and growth. To address this, we conducted a global meta-analysis using [XX] observations from [XX] journal articles, including data compiled from an existing database of plant functional trait responses to nitrogen and phosphorus addition. Our objectives were two-fold. First, we sought to quantify the effects of N, P, and N+P addition on net photosynthesis, photosynthetic capacity, leaf nutrient content and partitioning, resource use efficiencies, plant growth, and biomass partitioning. Second, we used these responses to make inferences about whether the effects of N+P addition are the product of additive, synergistic, or antagonistic individual effects of N and P addition. Meta-analysis results show that P addition increased leaf phosphorus content by XX%, a pattern that was mostly driven by an increase in the XX fractional pool.

**Introduction**

**Materials and Methods**

*Data sources*

Initial data for the meta-analysis were collected from the Manipulation Experiments Synthesis Initiative (MESI) database (Van Sundert et al., 2023). We selected field manipulation experiments that added N and P in a full-factorial design to ensure that any comparisons made between N, P, and N+P addition responses were from the same subset of experiments. As a supplement, data published from studies part of the Nutrient Network were included in the meta-analysis, again only selecting measurements collected from control, N, P, and N+P addition plots. Each site in the Nutrient Network dataset was treated as an independent experiment, following that the Nutrient Network is a globally distributed experiment where independent sites share a similar nutrient addition and experimental design scheme (Borer et al., 2014). Specifically, we added leaf nutrient data from Firn et al. (2019), biomass partitioning data from Cleland et al. (2019), and photosynthetic data from Hersch-Green et al. (2024).

We supplemented our compilation of measurements from the MESI database and Nutrient Network data by adding a series of additional field manipulation experiments using journal articles published online before January 2025. To compile these experiments, we created a complex query in Web of Science, adapting our approach using similar search terms adopted from (Liang et al., 2020). Specifically, our query mined for the following terms in the article title, abstract, or keyword list: (nitrogen AND phosphorus) AND (fertiliz\* OR addition) AND (effect\* OR respon\* OR affect\* OR impact\* OR increas\* OR decreas\* OR alter\* OR deposition OR enrich\*) AND (leaf nitrogen\* OR leaf phosphorus\* OR \*use efficiency OR biomass OR mass fraction OR root:shoot OR LMA OR SLA OR chlorophyll OR Vcmax OR Jmax) NOT (animal\* OR medic\* OR chemist\*). Search results for this query yielded 9,234 articles, which were further distilled to satisfy the following criteria:

1. Functional traits must be measured in plants growing in a field manipulation experiment. Data from greenhouse or growth chamber experiments were omitted from the meta-analysis to avoid any influence of pot size restricting growth, biomass partitioning, or investment toward photosynthesis
2. Nutrient manipulation experiment must add full-factorial combinations of N and P
3. Associated data for the manuscript were available (noted by checking the “Associated Data” tab in the Web of Science user interface)

These criteria rendered the addition of XX additional studies.

These criteria yielded XX additional observations from XX additional studies. The final size of the dataset, including the MESI database and Nutrient Network data, included XX observations from XX studies.

*Data extraction*

For observations included in the MESI database, means, standard deviations, and sample sizes of the control and nutrient addition treatment groups were readily available and used directly in the meta-analysis. For observations in the Nutrient Network data compilation, summary statistics for the control and nutrient addition treatment groups were determined for each trait at each site. Summary statistics for Firn et al. (2019) and Hersch-Green et al. (2024) were determined within each species, such that there was one mean, standard deviation, and sample size value for each individual measured within each treatment for each trait for each site.

the Nutrient Network data were pooled across species, such that there was one mean, standard deviation, and sample size for each treatment within each trait for each site. For additional experiments added through Web of Science, we calculated summary statistics for the control and nutrient addition treatment groups for each trait, again pooling the statistics across species such that there was one mean, standard deviation, and sample size value for each treatment.

Due to an abundance of articles that did not publish data alongside the article, we used the ‘metaDigitise’ R package to estimate summary statistics from plots when articles included sample sizes (Pick et al., 2019). A column is included in our compiled dataset that notes whether summary statistics were determined using actual data or estimates from plots.