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Experimental support for optimization of photosynthetic biochemistry and leaf gas exchange in response to combinations of rising CO_2, drought stress and phosphorous deficit.

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Current land surface models hold large uncertainties in the predictions of how key biosphere processes such as photosynthesis, respiration and transpiration will respond to the combined effects of rising atmospheric CO_2, nutrient enrichment and changes in water availability. Recent developments in optimality theory provide new approaches to explicitly predict coordinated changes in leaf photosynthetic traits, specifically stomatal conductance (g_s) and the maximum capacities of carboxylation (V_{cmax}) and electron transport (J_{max}) (*e.g.* Prentice *et al.*, 2014; Smith *et al.*, 2019; Harrison *et al.*, 2021). These novel formulations show promising results when tested with meta-analyses and global data sets. However, support from manipulative experiments that include changes in CO_2-growth conditions remains scarce. Here we summarize the results from two manipulative experiments using walk-in growth chambers in which a variety of species were exposed to sub-ambient, ambient and elevated growth CO_2 in combination with either a Phosphorous (P) treatment or a drought treatment, and compare the experimental results with predictions from optimality theory. The P treatment exposed plants to either severe P limitation at an N:P ratio of 45:1 or severe Nitrogen (N) limitation at an N:P ratio of 1:1, with a similar supply rate of N. The drought treatment consisted of a continuous dry-down after an initial period of unstressed establishment and growth. Results of the combined CO_2-nutrient treatment showed significant effects of growth CO_2 and P supply on V_{cmax} and J_{max}, as well as the whole-plant biomass at the point of harvest. Interaction effects between growth CO_2 and P supply were observed for g_s, the light-saturated photosynthesis rate, leaf P content, and the N:P ratio of the leaf. Results of the combined CO_2-drought experiment showed that g_s, V_{cmax} and J_{max} decreased significantly under rising CO_2 treatments, whereas whole-plant biomass at the point of harvest increased significantly. When scaled with non-stressed conditions, g_s and light-saturated photosynthesis declined consistently across CO_2 treatments. These experimental results align with quantitative predictions of g_s, V_{cmax} and J_{max} based on optimality theory. However, additional formulations are required to predict whole-plants growth responses as well as changes in plant nutrient-stoichiometry.

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