EGU22-1858
https://doi.org/10.5194/egusphere-egu22-1858
EGU General Assembly 2022

Photosynthetic acclimation under CO2 fertilization: new perspectives from current experiments

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Photosynthetic acclimation under CO_2 fertilization is still incompletely understood. Observed reductions in the maximum rate of carboxylation (V_{cmax}) and electron transport (J_{max}) under elevated CO_2 (often called 'down-regulation') have been explained in various ways, including limited soil nitrogen (N) and phosphorus (P) availability, or a reduced demand for N. However, there remains large variation of the V_{cmax} decline and some non-sensitive or even positive responses are documented. The least cost hypothesis (Prentice et al., 2014) states that optimal photosynthesis is achieved at balanced unit costs of capacities of carboxylation and transpiration and predicts the acclimation of V_{cmax} and J_{max} in response to the environment. Under elevated CO_2, V_{cmax} is predicted to decline, while the ratio J_{max}/V_{cmax} is predicted to increase - independent of N supply from the soil. In contrast, common model parametrisations conceive V_{cmax} to be controlled by soil N supply.

Here, we analyse a compilation of experimental results in an attempt to better understand photosynthetic acclimation to elevated CO_2 and balance the evidence for contrasting model formulations. Within 38 CO_2 fertilization plots investigated at forest, grassland and cropland, V_{cmax} and J_{max} are shown to decrease in concert, while the ratio J_{max}/V_{cmax} increases with higher CO_2 concentration, consistent with predictions from the least cost hypothesis. However, the predicted increase in the J_{max}/V_{cmax} ratio is too large and the observed change in V_{cmax} is correlated with the change in soil inorganic N. Observed leaf N responses are broadly consistent with changes in V_{cmax} and J_{max}. These findings support the idea acclimation of photosynthetic traits under enhanced CO_2 is modulated by soil N supply. This can be explained by the direct decline of soil N availability at higher CO_2 concentrations. However, it may also be caused by increase rates of net primary production (NPP) and N uptake that increase N sequestered in biomass under elevated CO_2, in such a way to constrain labile soil N available for leaf-level photosynthesis.

V_{cmax} and J_{max} responses to CO_2 were also found to be negatively related to increases of above- and below-ground net primary production (ANPP, BNPP). This pattern might be explained by a 'dilution effect', due to a CO_2-induced increase of leaf area index (LAI). However, it might also be due to plants having different stomatal responses to CO_2. According to this hypothesis, at one end of the spectrum, the ratio of leaf intercellular CO_2 (C_i) relative to ambient CO_2 (C_a) remains constant; optimal photosynthesis increases, while optimal V_{cmax} declines. At the other end of the spectrum, C_i/C_a decreases enough that C_i remains constant; then there is no increase in optimal photosynthesis, and no change in optimal V_{cmax}. Testing this hypothesis would require concomitant measurements of all of the relevant quantities (LAI, NPP, C_i/C_a) in multiple experiments.