Testing the responses and interplay of leaf physiological and morphological traits at elevated CO₂ levels in six common crop species

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Introduction

Biochemical optimality (EOO) states that plants adapt or acclimate to their environment thereby eliminating suboptimal plant strategies by natural selection. EOO has been proven successful for developing hypotheses and models of the terrestrial biosphere. On a plant level, EOO theory is used to analyze and model plant processes including photosynthesis, gas exchange, and stomatal behavior. Plants regulate their gas exchange by dynamically adjusting their stomata on a short term scale (opening and closing) and long term scale (growth and development of stomatal photographic capacity). The operational stomatal conductance ($G_s$) is determined by the opening state of the stomata during typical growth conditions. The anatomical maximum stomatal conductance ($G_{s,max}$) results from the maximum stomatal aperture, stomatal density and pore depth.

Methods

For the climate chamber, 9 plants per species were grown in 1 litre pots. Measurements started when first fully mature leaves appeared. Measurements were made with a LI-6400 portable photosynthesis system. Imprints of the outside for microscope analyses were made with nail varnish, to determine $G_{s,max}$.

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Morphological preliminary results

Biochemical preliminary results

Further analysis

- Analysis of the other species: $G_{s,max}$ and $G_{s,min}$
- All species: photosynthetic traits, $G_{s,max}$, $G_{s,min}$, and $A_{max}$
- Correlated with species response statistically
- Correlated with model simulations
- Integrate in optimality context

Outlook

- Connect this research to herbarium analysis to compare the results on different (longer) timescales
- Use results to test and improve the P-model
- Use results to identify potential plant physiological constraints in the P-model (based on paper 1 of thesis)

Conclusions

Plants adapt their biochemistry and morphology at elevated CO₂ levels. Photosynthesis traits, $G_{s,max}$ and $A_{max}$ decrease (Borlotti bean), while operational maximum photosynthesis rates increase (all species). Morphology, photosynthesis and stomatal conductance dynamically influence each other, as well as photosynthesis. This shows that different morphological and biochemical strategies can result in the same enhanced photosynthetic rate at elevated CO₂. It should also be noted that responses in morphology may be more consistent between species on longer timescales.

Combining biochemical and morphological responses: preliminary conceptual framework

See fig. 8. The two curves represent AC for a theoretical plant at ambient (AC) and elevated (HC) CO₂ levels. At elevated CO₂ levels, $V_{c,max}$ and $J_{max}$ decrease. $G_{s,max}$ decreases due to stomatal closing (blue diagonal line), but $A_{max}$ increases due to photostimulation at elevated CO₂ (red points). $G_{s,max}$ and $A_{max}$ are significantly increased at elevated CO₂ levels. $G_{s,min}$ slightly decreases, but not significantly. Both traits have a significant species effect.

Biochemical preliminary results (continued)

Fig. 4. Boxplot of maximum stomatal conductance ($G_{s,max}$) of the species. There is a significant species effect ($P < 0.05$).

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