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Modeling crop adaption to atm. CO_2 enrichment based on protein turnover and optional use of mobile nitrogen for growth or photosynthesis

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Abstract

Crop models are frequently used for extrapolation of crop biomass production and yield quality under elevated atm. CO_2 concentration ([CO_2]). The effect of [CO_2] enrichment was analyzed in various experimental systems with a wide range of crop species and under various environmental conditions. At least in C_3 plants one would expect that [CO_2] enrichment is beneficial for biomass production because photosynthesis is not CO_2 substrate saturated under current [CO_2]. However, due to multiple interactions of elevated [CO_2] with other environmental factors the characteristics of crop acclimation vary strongly in range and comprise higher biomass production, lower tissue nitrogen concentrations, altered yield quality, and increased water and nitrogen use efficiencies. The lower tissue nitrogen concentrations are widely seen as a key factor in plant adaption. Therefore, various hypotheses exist to explain the decreased tissue nitrogen concentrations but the mechanisms in terms of [CO_2] enrichment are still not clear. Also how to model crop adaption is not sufficiently solved, yet. Therefore, we developed a model to test the 'down regulation of photosynthesis' hypothesis. Based on the GECROS model that was embedded into the Expert-N model environment (XN-G) we developed a new canopy model that accounts for the dynamic turnover of photosynthetic active nitrogen in the leaf (XN-GN). Mobile nitrogen derived from protein degradation is then available for redistribution within the plant. In this way the plant can then optionally use the re-mobilized nitrogen either for growth or for the synthesis of new photosynthetic active nitrogen. Both the original and the new model were tested against data of spring wheat grown in a Mini-FACE system. The sensitivities of both models to [CO_2] enrichment were analyzed. Using the new model [CO_2] enrichment altered the depth distribution of protein, increased the root:shoot-ratio and the biomass production.

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Bibliography

Amthor, J. 2001. *Field Crops Research* 73, 1–34.

Biernath, C., Bittner, S., Klein, C., Gayler, S., Hentschel, R., Hoffmann, P., Högy, P., Fangmeier, A., Priesack, E. 2012 *European Journal of Agronomy,* submitted.

Högy, P., Brunnbauer, M., Koehler, P., Schwadorf, K., Breuer, J., Franzaring, J., Zhunusbayeva, D., Fangmeier, A. 2012. *Environmental and Experimental Botany,* accepted.

Högy, P., Fangmeier, A. 2008. *J Cereal Sci* 48, 580–591.

Priesack, E., Gayler, S., Hartmann, H. 2006. *Nutrient Cycling in Agroecosystems* 75, 1–13.

Priesack, E., Gayler, S. 2009. *Progress in Botany* 70, 195–222; Equation 35.

Thornley, J. 1998. Annals of Botany 81, 421-430.

Thornley; J. 2004. Annals of Botany 93, 473-475.

Yin, X., van Laar, H. 2005. *Crop Systems Dynamics*. Wageningen Academic Publishers.

Objectives

The two main objectives of our study are

(i) to analyze to which extent a trade-off between nitrogen usage either for structural growth or for optimal leaf photosynthesis could explain canopy acclimation to changing atmospheric [CO_2] and

(ii) to compare simulations using a static vertical distribution of leaf nitrogen (original GECROS, XN-G) with simulations by the new model that considers turnover of N_P and hence re-distribution of nitrogen in the canopy (modified GECROS, XN-GN).

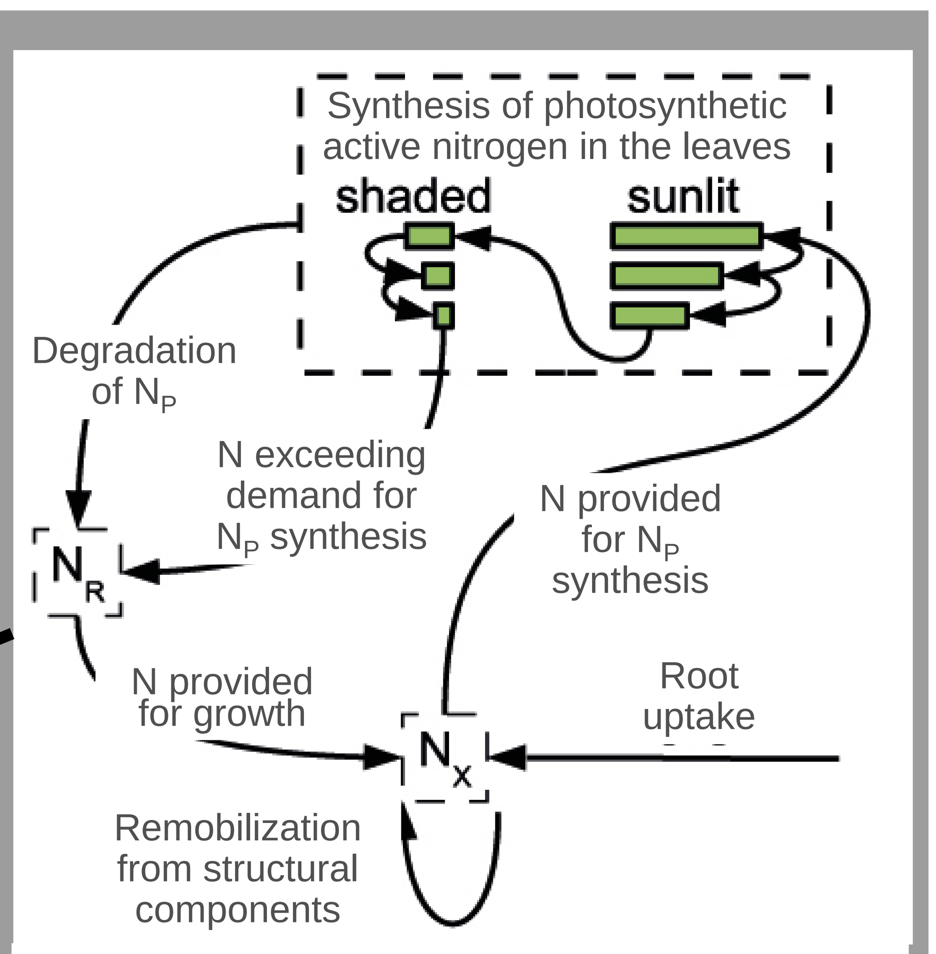

Fig.1: Plant internal nitrogen cycle of the modified GECROS model (XN-GN). Synthesis of photosynhtetic active nitrogen (N_P) occurs firstly in the sunlit leaves and secondly in the shaded leaves of the canopy. The green bars indicate different canopy laysers. Structural N (N_X). Storage N (N_R).

Morphological acclimation

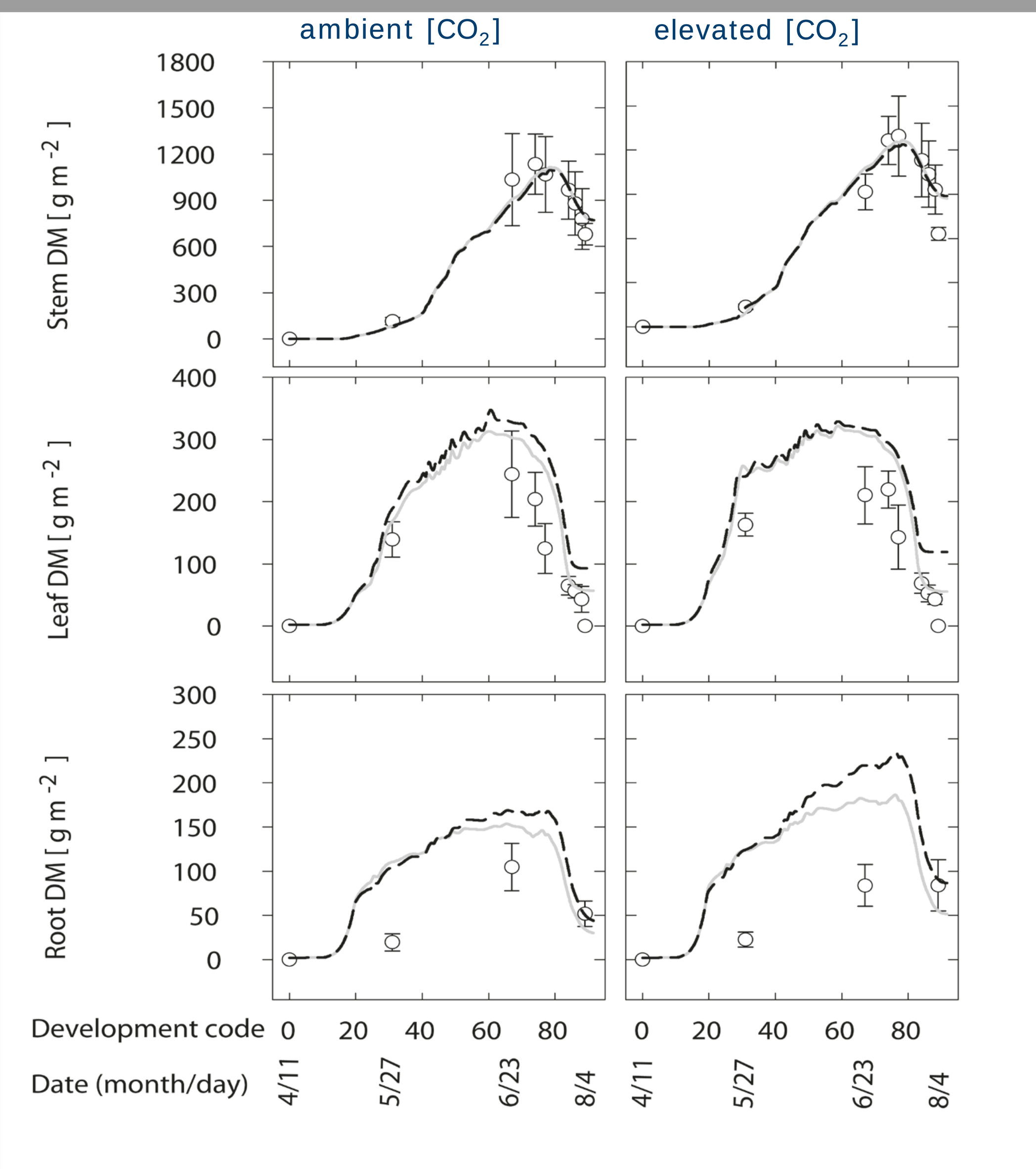

Fig.2: Dynamics of XN-GN (grey lines) and XN-G (black, dashed lines) simulations vs. Mini-FACE measurements (circles). Error bars are the standard deviation. DM: dry matter. Left panels: ambient [CO_2], right: ambient [CO_2]+150 ppm.

Physiological acclimation

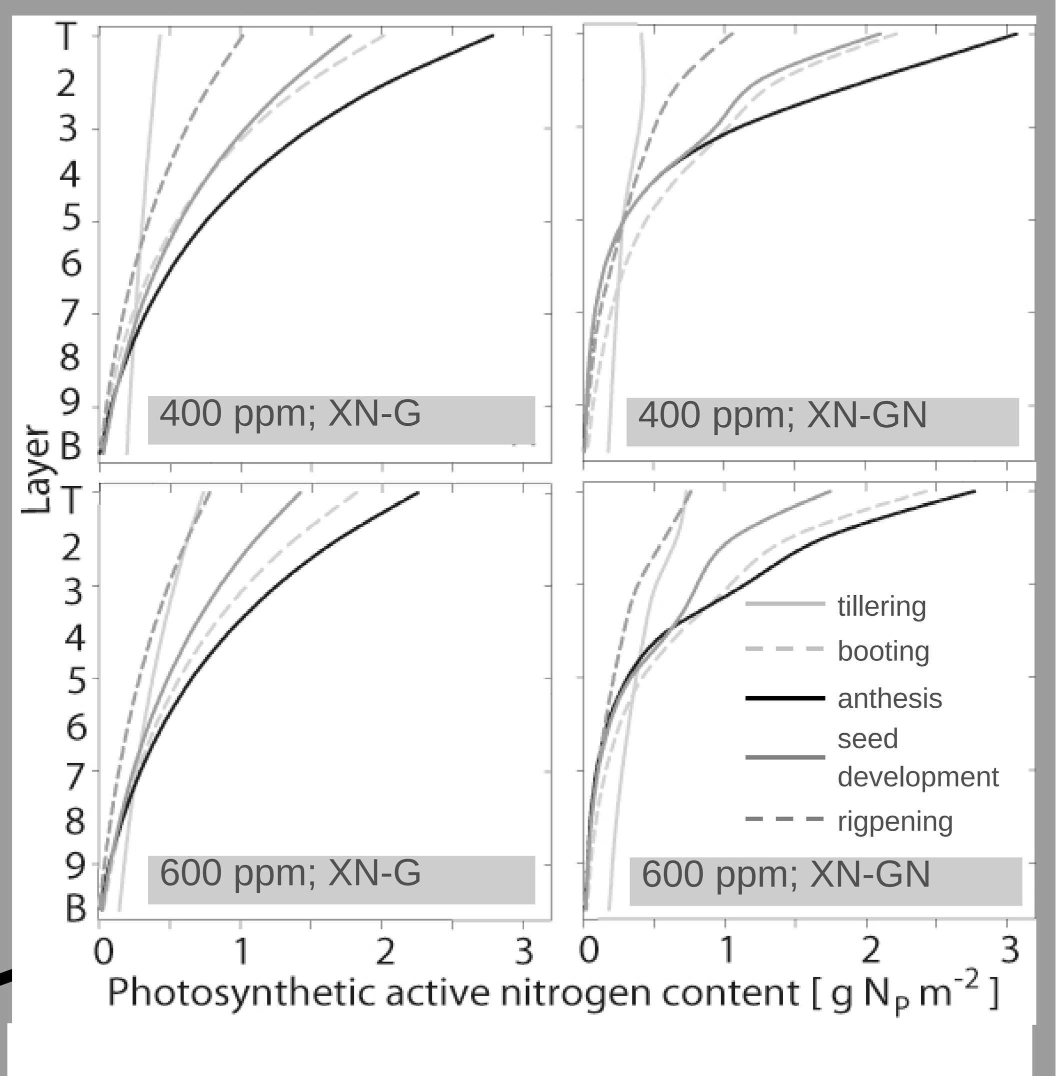

Fig.3: Vertical photosynthetic active nitrogen (N_P) dynamics within the canopy.

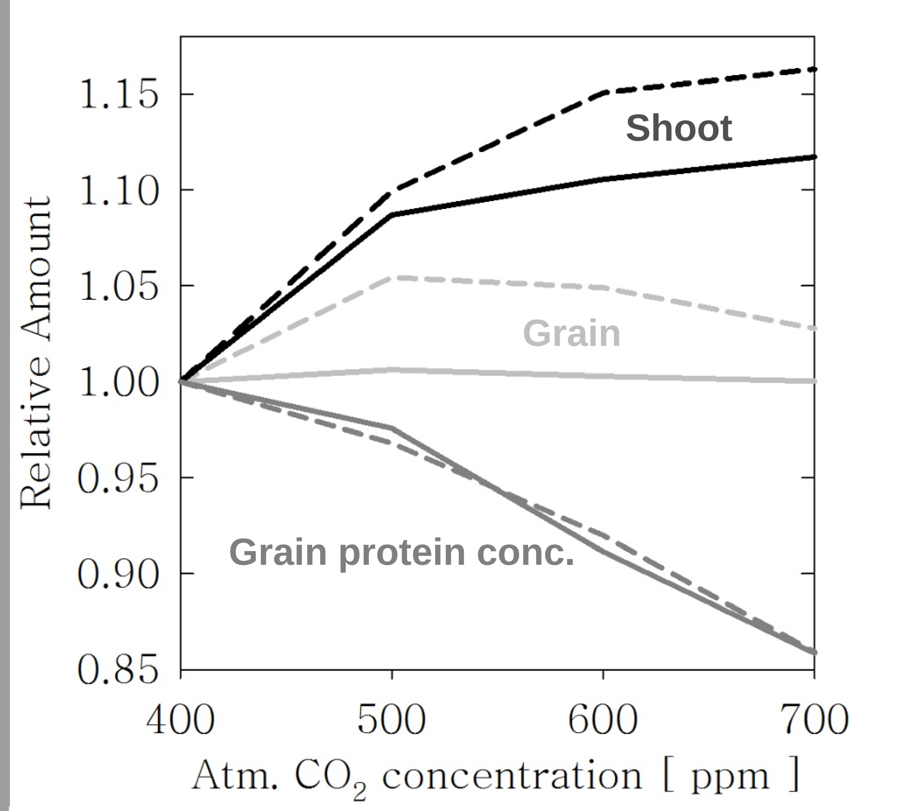

Fig.4: Relative effect of [CO_2] enrichment on crop traits using XN-G (solid lines) vs. XN-GN (dashed lines).

Results

- Crop acclimation to elevated [CO_2] needs to be modeled as a dynamic process that allows the trade-off between resource use either for growth or for the optimization of photosynthesis (Fig.1).
- XN-GN simulations show that the root:shoot-ratios increase with [CO_2] enrichment. This is a result of the model assumption. The root:shoot-ratio correlates with the C:N ratio in the plant. The C:N-ratio increases significantly stronger with [CO_2] enrichment in XN-GN simulations than in simulations by XN-G (Fig.2).
- The often used equilibrium assumption for the photosynthetic apparatus is not valid under the aspects of plant growth dynamics and changing environmental conditions, such as elevated [CO_2] (Fig.3).
- In XN-GN simulations biomass and yield increased stronger with [CO_2] enrichment, however no effect on grain protein concentration was observed, compared to XN-G simulations (Fig.4).

Conclusions

In GECROS, the root:shoot-ratio is proportional to the C:N-ratio in the plant (Priesack and Gayler, 2009). A more economic vertical NP distribution causes wider C:N ratios in XN-GN simulations under elevated [CO_2]. Predicted carbon sequestration to soils under future [CO_2] enriched climate conditions is lower in XN-GN simulations than using XN-G, but bioavailability is reduced due to wider C:N ratios.

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