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Meta-analysis of the response of crop photosynthesis to nitrogen limitation

Verena Seufert (1) and Christoph Mueller (2)

(1) Department of Geography, McGill University, Montreal, Canada, (2) Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

The carbon (C) and nitrogen (N) cycles are intricately linked at all spatial scales. At the smallest, molecular scale, the C and N metabolisms of organisms are interconnected due to the dependence of N acquisition on the C metabolism for the disposal of energy and C skeletons and the dependence of C acquisition on the N metabolism for the provision of proteins and other N compounds. The strong correlation between photosynthetic rate and leaf N content evidences the close relationship between C and N acquisition and represents a central connection between the C and N metabolisms that is used in many regional to global ecosystem models. This small-scale photosynthesis-leaf nitrogen relationship thus translates into the large-scale N control of the terrestrial C cycle.

Despite the importance of N as a major limiting nutrient in terrestrial ecosystems, the general response of photosynthesis and plant growth to N limitation is not yet well understood. Under suboptimal N conditions plants have two possibilities: reducing the leaf N content and the photosynthetic rate or reducing leaf area expansion while maintaining leaf N content relatively constant. So far no consistent picture about the relative importance of different strategies in the response of crops to N limitation has emerged and it thus remains unclear in what detail N limitation needs to be implemented in ecosystem and crop growth models. Is there a general strategy of crops or crop types in dealing with N limitation? To investigate this question, we used the meta-analysis technique to synthesize the literature on the response of 15 different crop species to N limitation. The meta-analysis focused on photosynthetic parameters, including photosynthetic rate, photosynthetic components, leaf N content and leaf area. In addition, the linear photosynthesis - leaf nitrogen relationship of crop species was analyzed in a meta-regression analysis to examine general patterns and differences between crop species and crop types.

Although meta-analysis has been widely used to examine the response of plants to elevated CO2 concentrations, so far to our knowledge no comprehensive meta-analytic review of plant response to N limitation has been conducted. This study shows that meta-analysis provides a useful tool to draw conclusions from the heterogeneous experimental literature on the effect of N limitation on physiological processes. The meta-analysis shows that crops under limiting N supply decrease the canopy size, accumulate less N, have lower leaf concentrations of proteins and chlorophyll, have a decreased photosynthetic rate, and show increased levels of leaf carbohydrates. Although leaf N content and photosynthetic rate are reduced significantly under N limitation, crop species differ in the extent in which they reduce photosynthesis compared to leaf area. The meta-regression analysis confirms the robustness of the linear relationship between photosynthetic rate and leaf N content for crops. It also shows that there are significant differences in the form of this relationship between crop species with different photosynthetic pathways. The form of the photosynthesis-leaf N relationship is influenced by environmental conditions like the level of CO2 or the level of N supply and this response differs between crop species. Although thus some general patterns in crop C-N interactions could be observed, the meta-analysis of the N limitation effect as well as the regression analysis of the photosynthesis-leaf N relationship show that crops in general or crop types do not follow a universal strategy in their response to N limitation. Crop species reduce their photosynthetic rate to differing degrees and invest differently in leaf N content and leaf expansion under limiting N supply.