Crop growth responses to free air CO_2 enrichment and nitrogen fertilization: rotating barley, ryegrass, sugar beet and wheat

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Model based projections of overall climate change effects on future crop yields strongly depend on the integration of the direct CO_2 fertilization effect. For European crops little information from field experimentation with elevated CO_2 levels ([eCO_2]) exists, which may be used for model validation purposes. Over six years an arable crop rotation with winter barley, ryegrass, sugar beet and winter wheat was exposed to ambient and elevated CO_2 levels (550 ppm) using a FACE facility under adequate nitrogen (N100) and 50% of adequate N fertilization (N50). Total plant N concentrations of all crops were lower between – 4.9% to – 17% under [eCO_2] compared to ambient CO_2. Green leaf area index (GLAI) of sugar beet and ryegrass late in the growing season was reduced by [eCO_2], while it slightly increased or remained unchanged for the cereals at anthesis. However, the results of total N and GLAI were statistically significant only for wheat and ryegrass. Final above-ground biomass and yield of all crop species significantly increased under [eCO_2]. Averaged across both growth seasons and N supply levels the stimulation of total above ground biomass by [eCO_2] amounted to + 14 % (barley), + 11.9% (wheat), + 10.6% (sugar beet) and + 9.9% (ryegrass). On average, cereal grain yield and storage root yield were enhanced by + 12.5% (barley), + 12.7% (wheat) and + 12.1% (sugar beet). There were no significant effects of [eCO_2] on N yield. Contrary to expectations, [eCO_2] effects on the plant growth variables were independent from the N supply level. Overall, growth and yield stimulations of the different crop species by [eCO_2] under FACE conditions were smaller than observed in many previous enclosure studies.

The implications of climate change for crop production and related to this the development of suitable adaptation measures are of high current concern. As the extent of future aerial "CO_2 fertilization" is crucial, albeit still highly uncertain, in model based assessments of climate change impacts, the data derived from the experiment described in this paper are of high relevance and novelty, respectively, for climate change impact modeling, particularly as the experimental approach including a crop rotation was as close as possible to current European agronomic practices. Once again, it was demonstrated that field studies may produce results (i.e. the extent of positive CO_2 effects) that differ from laboratory based approaches. Also, the growth enhancement by elevated CO_2 under optimal supply of other resources was small if compared to theoretical expectations based on the response of photosynthesis. This raises speculations whether current crop varieties may be unable to utilize the extra sugar assimilated by the source leaves of the plants under high CO_2 conditions and whether genotypes should be selected that could make optimal benefit from future atmospheric CO_2 levels. The lack of a clear CO_2 x N interaction advices caution with respect to generalizations of seemingly established mechanisms. The losses observed for plant N concentrations point to possible future problems with animal forage quality if atmospheric CO_2 levels continue to increase. Accordingly, the reduced plant N concentrations under high CO_2 concentrations raise questions if and to what extent the future N fertilization management of arable crops has to be adjusted to the new climate conditions.

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