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Response of aboveground grassland biomass and soil moisture to moderate long-term CO_2 enrichment

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Galium mollugo

Summary

Rising atmospheric CO_2 concentrations may alter C cycling and community composition, however, long-term studies in (semi-)natural ecosystems are still rare. In May 1998, the Giessen FACE (**F**ree **A**ir **C**arbon dioxide **E**nrichment) experiment started in a grassland ecosystem near Giessen, Germany, consisting of three enrichment (E plots) and three ambient control rings (A plots). Carbon dioxide concentrations were raised to +20% above ambient all-year-round during daylight hours. The wet grassland (*Arrhenatheretum elatioris* Br.-Bl.; not ploughed for >100 years) has been fertilized with 40 kg ha^{-1} yr^{-1} N, and mown two times each year for decades. Since 1993, the biomass has been monitored and since 1997 it was divided into grasses, legumes and non-leguminous forbs.

During the 5 years prior to CO_2 enrichment, the annual biomass yield from the A plots was non-significantly higher (3%) than the later E plots yield. Under CO_2 enrichment, the biomass increased significantly from the third enrichment year on by 9.8%, 7.7% and 11.2% in the years 2000–2002, respectively. The increase was surprisingly high considering the moderate CO_2 enrichment regime of only +20% and sub-optimal N supply, possibly suggesting a non-linear response of temperate grassland ecosystems to rising atmospheric CO_2 levels.

The leaf area index did not change significantly under elevated CO_2, nor did the soil moisture in the top 15 cm increase. No correlation existed between the magnitude of the yield stimulation under elevated CO_2 and the precipitation sums preceding the respective harvests. The grass biomass increased significantly under FACE, while the forb biomass declined strongly in the fourth and fifth year. The legume fraction was mostly below 1% of the total yield, and did not respond to CO_2 enrichment. These findings are in contrast to other grassland results and possible reasons are discussed.

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Zusammenfassung

Steigende atmosphärische CO_2-Konzentrationen könnten C-Umsatzprozesse und das Artengefüge von Pflanzengemeinschaften verändern. Langzeit-Studien an intakten, (halb-)natürlichen Ökosystemen sind dennoch selten. Im Mai 1998 startete das Gießener FACE-Experiment, bestehend aus drei Kontroll- (A plots) und drei CO_2-Anreicherungsringen (E plots), in denen die CO_2-Konzentration ganzjährig während der Tageslichtstunden um +20% erhöht wurde. Das mehr als 100 Jahre alte Feuchtgrünland (*Arrhenatheretum elatioris* Bl.-Bl.) wurde mit 40 kg $ha^{-1} a^{-1}$ N gedüngt und seit Jahrzehnten zweimal pro Jahr geschnitten. Seit 1993 wurden Ernten auf der Fläche durchgeführt, seit 1997 wurde in Gräser, Kräuter und Leguminosen differenziert. Der jährliche Biomasse-Ertrag der A plots war während der fünfjährigen Vorversuchsperiode nicht-signifikant höher als der Ertrag der (späteren) E plots. Durch die CO_2-Erhöhung stiegen die E-Erträge ab dem dritten Jahr signifikant um 9,8, 7,7 und 11,2% (2000–2002). Die Größenordung der CO_2-Antwort war überraschend hoch in Anbetracht der relativ geringen CO_2-Konzentrationserhöhung und suboptimalen N-Versorgung des Grünlands. Dies deutet möglicherweise auf eine nicht-lineare Antwort temperater Grünland-Ökosysteme auf die steigenden atmosphärischen CO_2-Konzentrationen hin.

Weder änderte sich der Blattflächen-Index, noch stieg die Bodenfeuchte durch die CO_2-Anreicherung an. Die Höhe der CO_2-Antwort der Biomasse war nicht mit der zuvor gefallenen Niederschlagsmenge korreliert. Die E-Gras-Biomasse stieg graduell und signifikant, während die Kräuterbiomasse im vierten und fünften Jahr stark abnahm. Die Leguminosen-Biomasse, i.d.R. unter 1% des Gesamtertrags, stieg nicht unter erhöhtem CO_2. Diese Ergebnisse unterscheiden sich von den Resultaten anderer CO_2-Experimente in Grassland-Ökosystemen und mögliche Ursachen werden diskutiert.

Introduction

Since 1750, the atmospheric CO_2 concentration has increased by 34% to a current mixing ratio of about 375 ppm today, and is expected to reach 540–970 ppm by 2100 (IPCC, 2001). The current concentration is the highest during the last 500,000 years (Augustin et al., 2004) and likely during the past 20 million years (IPCC, 2001). One of the key questions of eco-physiological CO_2 research during recent decades has been to assess to what extent the additional carbon will be sequestered into the standing biomass and soils of terrestrial ecosystems. For the period 1990–1999, it was calculated that 43.8% of the atmospheric CO_2 increase was sequestered into terrestrial ecosystems (IPCC, 2001). Research efforts have focused on various levels, i.e. how single plants, plant communities or ecosystems will respond to rising atmospheric CO_2 concentrations (Brown & Escombe, 1902; Strain & Bazzaz, 1983; Bazzaz, 1990; Poorter, 1993; Körner, 2000; Hamilton et al., 2002; Nowak et al., 2004b). However, the majority of CO_2 enrichment experiments have investigated the response of single plant species, especially crops, whereas studies dealing with well-established, natural or semi-natural multi-species plant communities are still rare (Körner, 2000; Nowak, Ellsworth, & Smith, 2004a). The stimulation of aboveground biomass due to elevated CO_2 concentrations is often weaker or even zero for well-established, nutrient limited ecosystems (Schäppi & Körner, 1996; Stöcklin, Schweizer, & Körner, 1998; Körner, 2000), or requires special circumstances, e.g. drought stress (Owensby, Ham, Knapp & Auen, 1999; Volk, Niklaus, & Körner, 2000; Morgan et al., 2004a, b) or the presence/absence of species to induce a positive growth response (Vasseur & Potvin, 1998; Niklaus, Leadley, Schmid, & Körner, 2001; Grünzweig & Körner, 2001a; Reich et al., 2001a). Yet it will be the long-term response of natural ecosystems such as grasslands that will finally determine if C sequestration into the biomass and the soil can mitigate some of the CO_2 increase (Batjes, 1998; Houghton, 1995). It is therefore pivotal to conduct long-term experiments in established ecosystems because it is still unclear how long it takes until a new steady state of the ecosystems' C and N cycles is reached after a step increase in the CO_2 concentration (Luo & Reynolds, 1999; Luo, 2001). The few available long-term (10–17 years) experiments suggest that several ecosystem reactions are weak or concealed at first but become more prominent over time (Daepp, Suter, Almeida, Isopp, & Hartwig et al., 2000; Schneider et al., 2004, Swiss FACE; Rasse, Peresta & Drake, 2005, Chesapeake Bay salt marsh).