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The Response of Soil CO_2 Efflux under Trees Grown in Elevated Atmospheric CO_2: A Literature Review

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Summary

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As elevated atmospheric CO_2 concentrations typically result in larger root systems and increased litter production, also soil CO_2 efflux is expected to be enhanced in elevated CO_2. In a review of the related literature we did find a mean stimulation of soil CO_2 efflux of 37 %, but large differences occurred among different experiments. In some experiments, soil respiration was not or even negatively affected, despite significant increases in root biomass. We hypothesize that the lack of response of soil CO_2 efflux to increased CO_2 concentrations in those experiments was due to a retardation of soil organic matter and possibly also litter decomposition.

Introduction

Increasing levels of atmospheric CO_2 may significantly alter the terrestrial carbon (C) cycle. Next to the stimulation of photosynthesis and biomass production, one of the major effects of elevated atmospheric CO_2 concentrations (pCO_2) is the relative increase in C allocation to roots and mycorrhizae (CEULEMANS & al. 1999), resulting in larger root systems (ROGERS & al. 1994). The enhanced root biomass, and the stimulated delivery of labile C into the soil are likely to increase both the accumulation of C in the soil and the efflux of CO_2 from it.

Globally, the efflux of CO_2 from the soil (SCE) is roughly ten times larger than the anthropogenic emissions (SCHIMEL 1995). Thus, changes in root respiration and soil organic matter decomposition induced by elevated pCO_2 and

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rising temperatures might significantly influence the Earth's C cycle and the global climate. Here we present a literature review on the effects of elevated pCO_2 on SCE, and will try to explain the observations.

Results

Three significant observations were detected in the reported studies. Firstly, an increase in SCE was observed in response to CO_2 enrichment in most of the reported studies (Table 1), with an average stimulation of 37 %. However, several studies showed no stimulation, and even decreases in SCE were reported. Secondly, in all studies with multiple pCO_2 levels, the increase in pCO_2 from ambient to the first level always had a larger effect on SCE than the increase from that first level to a higher level (Table 1). Thirdly, the stimulatory effect changes considerably in time, with large intra- and interannual variability (data not shown).

Discussion

Elevated pCO_2 significantly stimulates root growth and root biomass (ROGERS & al. 1994), and rhizosphere respiration has been found to be very responsive to elevated pCO_2 (CHENG 1999, LIN & al. 1999). The observed decrease in SCE in some experiments is therefore an unexpected result. In the studies on *Fraxinus excelsior*, *Quercus petraea* and *Pinus sylvestris* by M. Broadmeadow (Table 1), root growth more than doubled (CROOKSHANKS & al. 1998), while soil respiration was unaltered or even decreased. In the experiment on *Fagus sylvatica* saplings (LE DANTEC & al. 1997), root biomass increased with 30 %, but SCE nevertheless decreased by 10 % (Table 1). Furthermore, also in several experiments where SCE did significantly increase, this stimulation was still small compared to the effect on root biomass. In the study on *Pinus sylvestris* (JANSSENS & al. 1998), e.g., SCE increased significantly by 25 %, but fine root biomass increased by 135 %.

Part of this discrepancy is related to the fact that root respiration is only a fraction of total SCE, and therefore a doubling of root biomass will not lead to a doubling of SCE. In addition, biomass produced under high pCO2 is usually characterised by reduced N concentrations (COTRUFO & al. 1998), possibly resulting in a reduction of specific root respiration rates (RYAN & al. 1996). Although these arguments may explain why the stimulation of SCE is smaller than the stimulation of rhizosphere respiration, it cannot explain the reported decreases. Thus, the negative and small responses suggest that (in some cases) elevated pCO_2 may negatively affect decomposition of litter or soil organic matter (SOM).

It has been hypothesised that the reduced litter N concentrations would retard their decomposition in the initial stages. Since most of the studies in Table 1 were short-term, the deposited litter may still have been in these initial stages of decomposition, and thus decomposing at a slower rate. This may have contributed to the moderate response of SCE observed in some studies. However, because of the relatively small litter production in these young ecosystems and the long turnover periods of the produced litter, it seems unlikely that the potentially retarded litter decomposition rates significantly reduced the response of SCE. We therefore suggest that, under certain conditions, retarded SOM decomposition rates can offset the increase in rhizosphere respiration. Reduced rates of SOM decomposition have indeed been found in some studies (although not in many others), but the conditions under which this reduction occurs remain unclear (CHENG 1999). The effects of exudation and soil nutrient status on the mineralisation of SOM, and the competition for nutrients between plants and microbes appear to be of major importance.

Table 1. Responses of soil CO_2 efflux under CO_2-enriched trees. For each study, also growth conditions, pCO_2 and the reference are given. (OTC's = open top chambers; GH = greenhouse, A = ambient). We calculated means for studies where results were reported separately for different measurement periods.

Species	Conditions	pCO_2	Mean E/A	Reference
Acer rubrum	OTC's	A, 700	1.27	(EDWARDS & NORBY 1999)
Acer saccharum	OTC's	A, 700	1.05	(EDWARDS & NORBY 1999)
Betula pendula	OTC's	A, +350	1.95	(REY & al. 1997)
Castanea sativa	GH	A, 700	1.53	(ROUHIER & al. 1996)
Fagus sylvatica seedlings	Open-sided growth chambers	A, +350	2.71 (high N) 1.41 (low N)	(LE DANTEC & al. 1997)
Fagus sylvatica saplings	Open-sided growth chambers	A, +350	0.90	(LE DANTEC & al. 1997)
Fraxinus excelsior	OTC's	A, +350	1.10	(BROADMEADOW unpubl.)
Liriodendron tulipifera	OTC's	A, 500, 750	1.25 1.22	(NORBY & al. 1992)
Macchia vegetation	OTC's	A, +350	1.13	(DE ANGELIS & al. unpubl.)
Picea abies	Microcosms	280, 420, 560	1.13 1.18	(HÄTTENSCHWILER & KÖRNER 1997)
Pinus ponderosa	OTC's, low N	A, 525, 700	1.57 1.93	(JOHNSON & al. 1994)
Pinus ponderosa	OTC's, high N	A, 525, 700	1.44 1.33	(JOHNSON & al. 1994)
Pinus ponderosa	OTC's	A, 525, 700	1.67 1.35	(VOSE & al. 1997)
Pinus sylvestris	OTC's	A, +350	1.25	(JANSSENS & al. 1998)
Pinus sylvestris	OTC's	A, +350	0.98	(BROADMEADOW unpubl.)
Pinus sylvestris	OTC's	A, 525	1.54	(PAJARI 1995)
Pseudotsuga menziesii	Microcosms	A, +200	1.15	(LIN & al. 1999)
Quercus alba	OTC's	A, 500, 750	1.22 1.37	(NORBY 1996)
Quercus petraea	OTC's	A, +350	1.03	(BROADMEADOW unpubl.)
Tropical forest	Microcosms	A, 610	1.89	(KÖRNER & ARNONE 1992)

DE ANGELIS & CHIGWEREWE measured SCE at three-weekly intervals for three years in a mature Mediterranean macchia vegetation growing in OTC's (DE ANGELIS & SCARASCIA-MUGNOZZA 1998). These authors observed a small and non-significant increase in the first and third year, whereas in the second year they found a large stimulation. The effect of pCO_2 on SCE fluctuated strongly and negative responses were observed even within the second year. These temporal fluctuations may be an important source of error in studies based on few measurements, and may have contributed to the variability among these studies.

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