Changes in the photosynthetic apparatus of European beech and Norway spruce under long-term exposure to elevated CO_2

Holišová P.[1], Šprtová M.[1], Kubásek J.[1], Lhotáková Z.[2], Mašková P.[2], Lipavská H.[2], Kočová M.[3], Holá D.[3], Radochová B.[4], Albrechtová J.[2], Urban O.[1]

[1]Global Change Research Centre, AS CR, Bělidla 4a, CZ-60300 Brno, Czech Republic
Charles University in Prague, Faculty of Science, [2]Department of Experimental Plant Biology and [3]Department of Genetics and Microbiology, Viničná 5, CZ-128 43, Prague, Czech Republic
[4]Institute of Physiology, AS CR, Department of Biomathematics, Vídeňská 1093, CZ-142 20 Prague, Czech Republic
E-mail: holisova.p@czechglobe.cz

Background

The changes of photosynthetic performance caused by increasing CO_2 concentration are reflected at different hierarchical levels of photosynthetic apparatus from the efficiency of individual photosynthetic processes to changes in leaf structure.

Aim

☺ to elucidate the relationships between the ultrastructure and function of photosynthetic apparatus under elevated CO_2 concentration

Material and study site

- The experimental research site **Bílý Kříž** in the Beskydy Mts. (908m a.s.l.) - a cool (annual mean air temperature 6.8°C) and humid (annual mean relative air humidity 83%) area with high annual precipitation (1356 mm).
- Two glass dome facilities – with **ambient** (AC; 385 ppm) **elevated CO_2** concentration (EC; 700 ppm) since 2007
- Two tree species broadleaved **European beech** (*Fagus sylvatica* L.) and coniferous **Norway spruce** (*Picea abies* (L.) Karsten) were planted as 2 years old in autumn 2005

gas-exchange

		Fagus sylvatica		*Picea abies*	
		AC	EC	AC	EC
H	m	2,5 ± 0,4	2,7 ± 0,5	1,5 ± 0,3	1,6 ± 0,2
$D_{0,3}$	mm	22,2 ± 3,0	22,5 ± 4,1	23,9 ± 4,0	24,2 ± 4,2
N	mg g^{-1}	24,7 ± 1,8	20,9 ± 2,1 *	15,4 ± 1,3	12,3 ± 2,1 *
C	mg g^{-1}	483,0 ± 8,9	478,7 ± 5,1	482,5 ± 4,4	486,8 ± 4,7
SLA	m^2 kg^{-1}	15,1 ± 1,5	13,6 ± 3,9	8,7 ± 1,5	8,2 ± 0,9

Table: Mean values ± standard deviations of physiological parameters of trees grown at ambient (AC) and elevated atmospheric CO_2 concentration (EC) in 2010: *H* -average tree height, $D_{0,3}$ - average stem diameter, N, C – nitrogen and carbon content per dry mass unit, SLA – specific leaf area. * - statistically significant differences $p \leq 0.05$

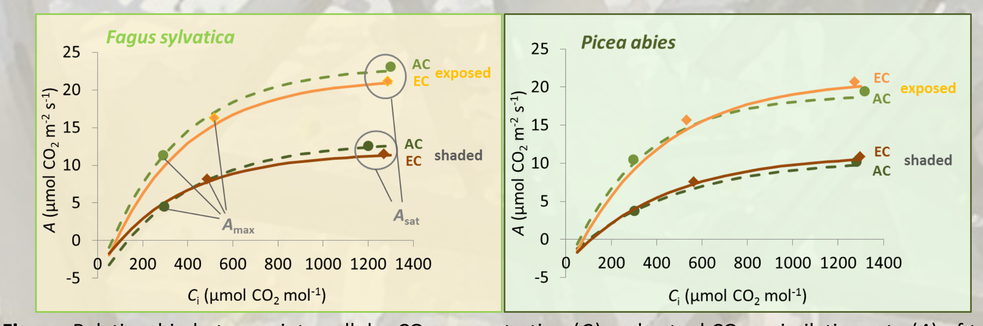
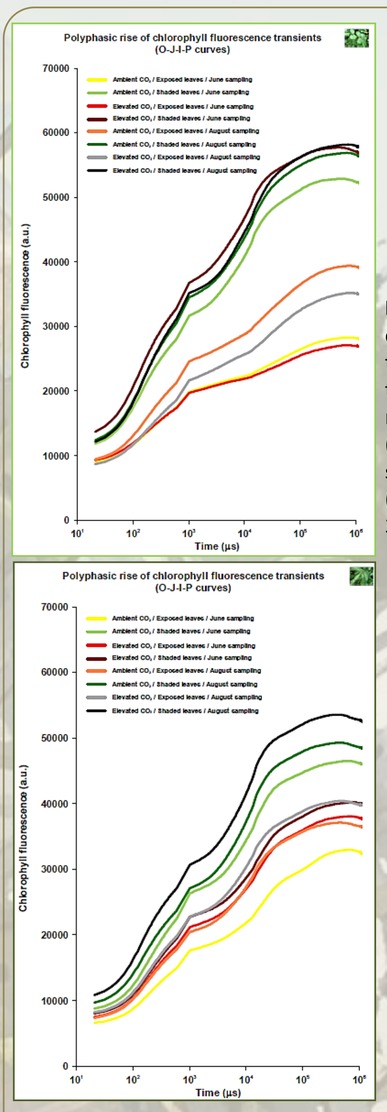


Figure: Relationship between intercellular CO_2 concentration (C_i) and actual CO_2 assimilation rate (*A*) of trees grown at ambient (AC) and elevated atmospheric CO_2 concentration (EC) on exposed and shaded leaves. Average curves from august 2011 were fitted by a nonrectangular hyperbolic function. The light-saturated CO_2 assimilation rate at growth CO_2 concentration (A_{max}) and the assimilation capacity (A_{sat}) are marked.

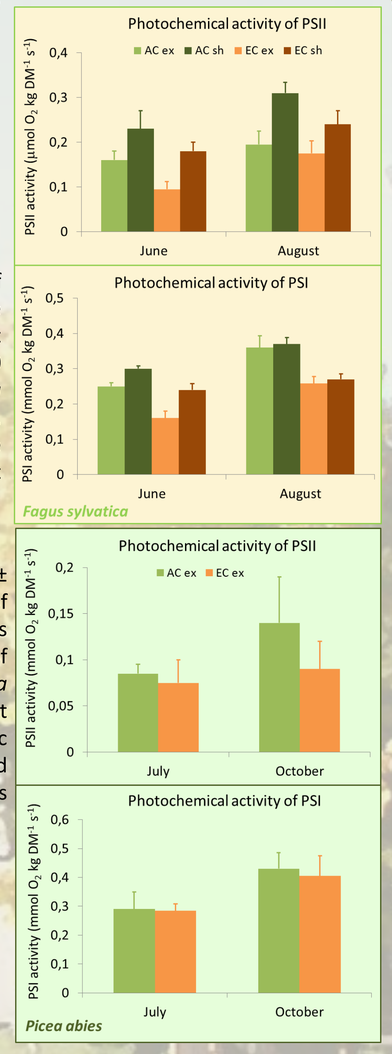
- EC treatment led to decrease in N content on average 20%.
- Beech are higher and had more N on dry mass unit than spruce.
- A_{max} is stimulated by EC treatment more in shade leaves as compared to exposed ones, particularly in spruce.
- Decrease in A_{sat} is more frequently observed in beech and it is usually accompanied by by slight decrease in a rate of CO_2 carboxylation and/or a rate of electron transport.

chlorophyll *a* fluorescence



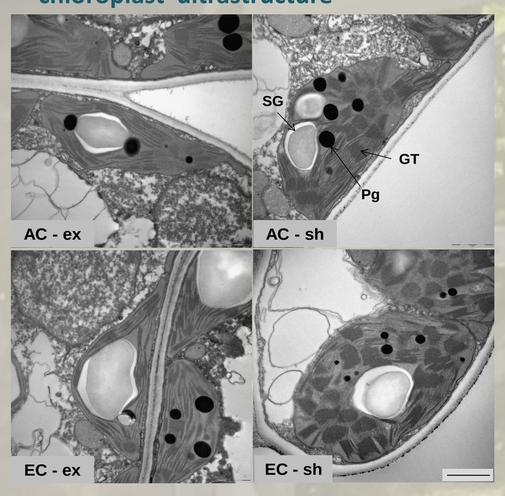
Left figures: Polyphasic rise of chlorophyll *a* fluorescence transients (OJIP curves) at ambient temperature of dark- adapted (20 min) leaves, *Fagus sylvatica* (upper) and *Picea abies* (lower), sampled in 2011. Saturating pulse (blue light, 455 nm) was set at 3000 µmol m^{-2} s^{-1}.

Right figures: Mean values ± standard deviations of photosystem (PS) I and II activities expressed per dry mass unit of *Fagus sylvatica* (upper) and *Picea abies* (lower) grown at ambient (AC) and elevated atmospheric CO_2 concentration (EC), exposed (ex) and shaded (sh) leaves sampled in 2011.



- Responses of primary photosynthetic reactions to EC treatment were larger in spruce than beech.
- Responses differed when the results were expressed per dry mass unit and per chlorophyll content unit. Effect of EC on PS II activities were diminished per chlorophyll unit and also effect of EC on PS I activities in beech, but in spruce PS I activity per chlorophyll content was higher under EC condition as compared to AC.

chloroplast ultrastructure



- Starch accumulation was higher in leaves of both species grown under EC, in spite of large variability
- Ultrastructure of chloroplasts responded more to light environment (exposed/shaded) than to CO_2 enrichment.
- Responses of chloroplast ultrastructure to EC treatment were larger in beech than spruce.
- Amount of plastoglobuli increased in mature leaves of beech, but under EC condition to a lesser extent than under AC.

Figure: Examples of micrographs from transmission electron microscope show chloroplasts of *Fagus sylvatica* grown at ambient (AC) and elevated CO_2 concentration (EC) and exposed (ex) and shaded leaves (sh), sampled in august 2011. SG – starch grain, Pg – plastoglobuli, GT – granal thylakoid. Bar means 1mm.

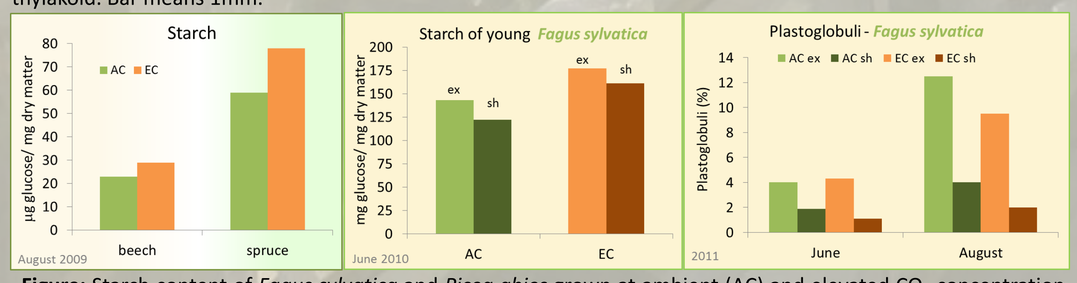


Figure: Starch content of *Fagus sylvatica* and *Picea abies* grown at ambient (AC) and elevated CO_2 concentration (EC), exposed (ex) and shaded (sh) leaves quantified by HPLC. Area estimation of plastoglobuli in beech chloroplast viewed by transmission electron microscope.

Conclusions

- Both tree species responded to EC differently.
- Spruce responded to EC more at the level of primary photosynthetic reaction while beech responded more by changes in chloroplast ultrastructure.
- Photosynthetic down-regulation was observed more often in beech compared with spruce. It will be likely due to N limitation, because beech has higher tree height and N content per leaf dry mass than spruce.

Methods

- Photosynthetic parameters were obtained using the gas-exchange system LI-6400 (LI-COR, USA).
- Characteristics of chlorophyll a fluorescence were obtained *in vivo* with FluorPen FP100max (PSI, CZ) and in vitro polarographically in suspension of isolated chloroplasts.
- Non-structural soluble saccharides and starch accumulation was quantified using HPLC.
- Chloroplast ultrastructure was quantified by stereological methods (Ellipse 2.08, SK) on the images acquired JEOL JEM-1011 (JEOL, JP).
- The *in vivo* measurements and samplings in different extent started in August 2009 on exposed branches of 10 trees per each treatment and continued on exposed and shaded leaves during June / August (beech) and July / October (spruce) 2010 to 2012.

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