

Photosynthetic Acclimation to Elevated CO₂ in Soybean

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Abstract

Previous studies on plant responses to elevated atmospheric CO₂ concentration [CO₂] found the occurrence of elevated [CO₂]-induced photosynthetic acclimation. Soybean cultivar Enrei was grown in pots and was subjected to either ambient [CO₂] (ca. 380 μmol mol⁻¹) or elevated [CO₂] (ca. 580 μmol mol⁻¹) regime. The half of the plants were transferred to the other [CO₂] regime at flowering. Under elevated [CO₂], photosynthetic rate was markedly enhanced at the early growth stage, whereas it was decreased at the later growth stage on both transferred and untransferred plants, indicating that the acclimation occurred at the later growth stage of the plants regardless of the transfer. Electron transport rate (ETR) curve of the plants under elevated [CO₂] regime became plateau at about 300 μmol mol⁻¹ intercellular [CO₂] at the later growth stage (35 days after transfer (DAT)), which was less than the plateaued value under ambient [CO₂] regime (320 μmol mol⁻¹), indicating that the acclimation of photosynthesis occurred due to decreased intercellular [CO₂] which might be restricted by the decrease in stomatal conductance, N or chlorophyll content in leaves. Moreover, the leaf N and chlorophyll content (SPAD reading) of the plants grown under elevated [CO₂] regime was lower than those of the plants grown under ambient [CO₂] regime at the later growth stage (80 days after sowing (DAS)/32 DAT). Thus the acclimation of photosynthesis of soybean appeared to be induced by decreases in stomatal conductance, N or chlorophyll content in leaves, although other factors such as starch accumulation in leaves at the later growth stage, which can restrict Rubisco activity in leaves, might be involved in the acclimation. Further research is needed to examine how other possible factors are involved in the acclimation of photosynthesis.

Keywords: elevated [CO₂]; photosynthesis.

Introduction

Increasing [CO₂] in the atmosphere will offset increased photorespiration by increasing photosynthesis, especially in plants with C₃ photosynthetic pathway. To examine environmental effects including the effect of increasing [CO₂] on soybean growth and development is very important, because plants develop and grow properly in proper conditions environmentally and genetically.

A number of previous studies showed that elevated [CO₂] affected photosynthetic behavior of crops such as soybean. Many previous studies showed positive responses of soybean to elevated [CO₂] (Rogers et al. 1997; Kimball et al., 2002; Pritchard and Amthor, 2005; Alagarswamy et al., 2006), but some other studies found down-regulation of photosynthesis under elevated [CO₂] (Sim et al. 1998; Sawada et al. 2001; Ainsworth et al. 2004; Kanemoto et al. 2009; Matsunami et al. 2009; Otera et al. 2011). The objective of the present study was to examine how the acclimation of photosynthesis occurs in soybean under elevated [CO₂].

Phenomenon of photosynthetic acclimation in plants can be ascribed to several factors. Several previous studies reported that acclimation of photosynthesis occurred for different reasons. Firstly, N limitation in leaves may cause photosynthetic acclimation (Kanemoto et al. 2009; Antal et al. 2010). Secondly, starch accumulation in leaves reduced Rubisco activity and induced photosynthetic acclimation (Sims et al. 1998; Sawada et al. 2001). Thirdly, balance in sink and

source affected photosynthetic acclimation (Rogers et al. 1998; Ainsworth et al. 2004). Fourthly, decrease of chlorophyll content or Rubisco activity in leaves may affect photosynthetic acclimation (Hotta et al. 1987; Sage et al. 1989). Finally, growth temperature induced photosynthetic acclimation in some C₃ species (Yamori et al. 2005).

Materials and Methods

A soybean cultivar Enrei (normally nodulating) was used in this study. Four seeds per pot (7 L) were sown on 6 June 2010 then thinned to one plant after emergence. Every pot was applied 6 g of compound fertilizer (N-P₂O₅-K₂O: 5-15-20) and 10 g of garden lime. The amount of each element per pot was N-0.3 g, P₂O₅-1.5 g, K₂O-1.2 g and SiO₂-2.8 g, Ca-0.4 g and Mg-0.4 g. The seeds were inoculated with *Bradyrhizobium japonicum* strain. The soil used was low-humic Andosol type. The plants were grown in the temperature gradient chambers (Gradiotron) of National Agricultural Research Center for Tohoku Region, Morioka, Japan, during June to October in 2010. There were two levels of [CO₂] inside the chamber: ambient (380 μmol mol⁻¹) and elevated (580 μmol mol⁻¹). The half of plants were transferred into the different [CO₂] regime (from ambient to elevated (A-E) or from elevated to ambient (E-A)) at flowering (48 DAS (R1)). The [CO₂] and temperature around plant canopy were monitored every half hour by sensors which were installed above the plots.

Measurement of photosynthesis was conducted at 2 DAT and 35 DAT. Chlorophyll fluorescence was determined by using portable photosynthesis system (LI-6400-40 with leaf chamber fluorometer, LI-cor Inc., NE, USA). The air flow to the chamber was controlled at 500 μmol s⁻¹. The measurements were conducted at saturated PPFD (1,500 μmol m⁻² s⁻¹). The photosynthetic measurement was conducted at varying [CO₂] with a range of 100 – 1,250 μmol mol⁻¹ (A-Ci curve). The values used for the calculation of ETR are as follows; maximal fluorescence (*F_m'*), steady-state fluorescence (*F_s*) and photosystem II efficiency (PhiPS2) with equation $\left[\frac{F_m' - F_s}{F_m'} \right]$. ETR was

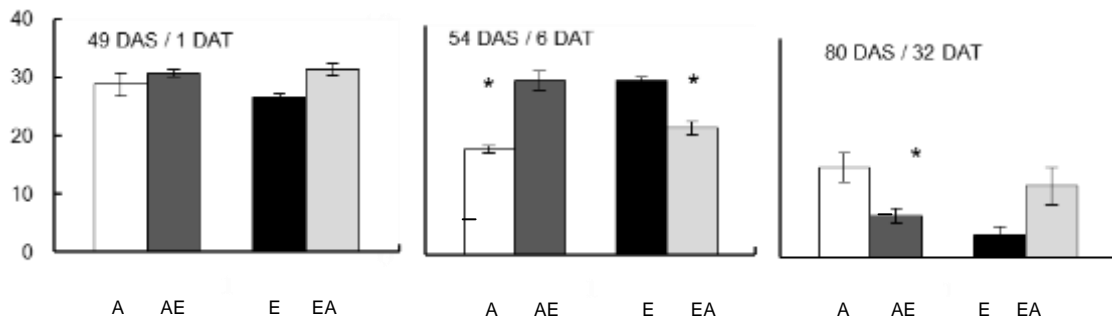
determined by the equation $\left[\frac{F_m' - F_s}{F_m'} \right] \cdot [fI\alpha_{leaf}]$,

where *f* is fraction of absorbed quanta that is used by PSII, and is typically assumed to be 0.5 for C₃ plants, *I* is incident PPFD (1,500 μmol m⁻² s⁻¹), *α_{leaf}* is leaf absorptance which is assumed to be 0.85 (Genty et al. 1989). Measurements were conducted on the plants which were transferred (A-E, E-A) and untransferred (A-A, E-E). Two to three plants for each plot were used for the measurements.

Results and Discussion

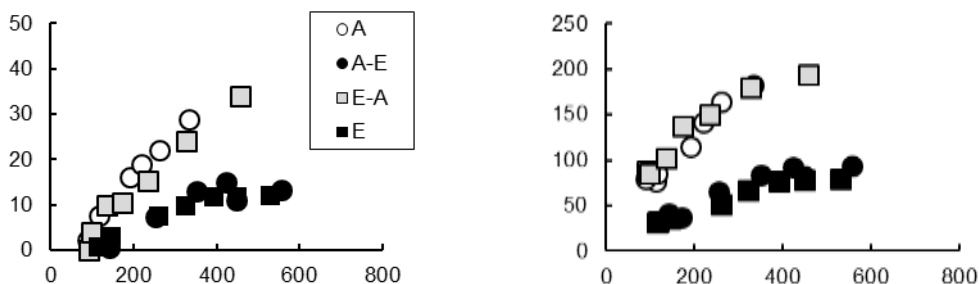
Under elevated [CO₂], photosynthetic rate was markedly enhanced at the early growth stage, whereas it was decreased at the later growth stage on both transferred and untransferred plants (Fig. 1), indicating that the acclimation occurred at the later growth stage of the plants regardless of the transfer. Electron transport rate (ETR) curve of the plants under elevated [CO₂] regime became plateau at about 300 μmol mol⁻¹ intercellular [CO₂] at the later growth stage (35 days after transfer (DAT)), which was less than the plateaued value under ambient [CO₂] regime (320 μmol mol⁻¹) (Fig. 2), indicating that acclimation of photosynthesis occurred at about 300 μmol mol⁻¹ intercellular [CO₂] probably due to decreased RuBP regeneration (Sharkey et al., 2007) which was affected by decrease in stomatal conductance (Fig. 3). Moreover, the leaf N and chlorophyll content (SPAD reading) of the plants grown under elevated [CO₂] regime was lower than those of

the plants grown under ambient [CO₂] regime at the later growth stage (80 days after sowing (DAS)/32 DAT) (data not shown).



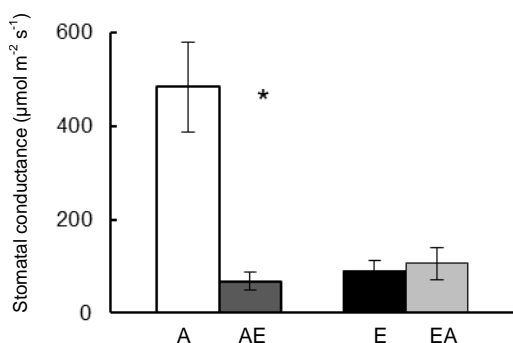
Measurements were conducted at saturated PPFD ($1,500 \mu\text{mol m}^{-2} \text{s}^{-1}$) under respective [CO₂] (A and E). Vertical bars indicate SE of three or five plants. *: significantly different at the 5% level between A and E [CO₂] regimes.

Figure 1. Photosynthetic rates of transferred (AE, EA) and untransferred (A, E) plants at the early growth stages (49, 54, and 80 DAS).



Fluorescence measurements were conducted at saturated PPFD ($1,500 \mu\text{mol m}^{-2} \text{s}^{-1}$).

Figure 2. Photosynthetic rate and electron transport rate at 2 DAT and at 35 DAT of transferred (A-E, E-A) and untransferred (A-A, E-E) plants.



Measurements were made in the morning at 80 DAS/32 DAT.

Figure 3. Effects of [CO₂] (A, E) on stomatal conductance of leaves.

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