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Photosynthesis and Respiration of Japanese Larch (*Larix kaempferi* Sarg.) -Continuous Measured with a Multichannel Automated Chamber System-

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Abstract

Our purpose is to estimate stand level photosynthesis by exploring leaf photosynthesis. We developed a fast-response system with 24 chambers that connected in parallel to a single CO_2 analyzer equipped with a 24-channel gas sampler to sequentially measure leaf photosynthesis at various canopy positions. The cylinder design chambers can completely envelop a segment of shoot with several twigs. Between measurements the chamber is opened to allow wind to pass through the chamber and prevent temperature increase inside the chamber. During the measurement, the chamber is closed and the change in CO_2 concentration inside the chamber is measured. The sampling period for each chamber is set to 150 s, and running a measurement cycle through 24 chambers takes just 1 h. Between August and September 2003, the system was installed in a 50-year-old Japanese larch forest and 10 trees were sampled. Canopy light saturated photosynthesis was 4.5 ± 1.2 μmol m^{-2} s^{-1}, and photosynthetic light use efficiency was about 0.021. Nighttime (dark) respiration was 0.6 ± 0.4 μmol m^{-2} s^{-1}, and respiration Q_{10} was about 7.5.

Key words: Automated chamber, Photosynthesis, PPFD, Respiration, Temperature

1. Introduction

Leaf photosynthesis has a remarkable influence on the global atmospheric CO_2 concentration. Accurate measurement of photosynthesis and respiration is therefore critical in the context of modeling carbon cycle dynamics of a forest ecosystem. Ecosystem level photosynthesis is generally measured with the recent micrometeorological technique (Baldocchi *et al.* 1997) or modeled from computing the chamber-based leaf level photosynthesis (Farquhar *et al.* 1980), each with their advantages and limitations. The micrometeorological technique has the advantages of continuous monitoring net ecosystem exchange (NEE), the sum of photosynthesis and ecosystem respiration, without disturbing the microenvironment around the leaves. However, it typically requires specific atmospheric and topographical conditions as well as quality checking and modeling of the missing data.

The biological process model of Farquhar *et al.* (1980) is most widely used to scale up stand level photosynthesis based on the chamber measurement of leaf photosynthesis. The model is easy to parameterize with the commercially available portable chamber system, but the sampling errors through small sample size and discontinuous measurement generally burden the validity of modeled estimation.

Our study aims: (1) continuous measuring of leaf photosynthesis and dark respiration at various canopy positions through the whole growing season by utilizing a multichannel automated chamber system, and (2) estimating stand level photosynthesis by exploring the chamber-based measurements.

2. Materials and Methods

2.1 Study site

The experiment was carried out during August and September 2003 at the Tomakomai flux site (lat 42°44'N, long 141°31'E), Hokkaido, Japan. The forest is a 50-year-old Japanese larch (*Larix kaempferi* Sarg.) monoculture plantation with canopy height of about 15 m. Information of the study site has been described in detail by Liang *et al.* (2004). We developed multichannel automated chamber systems for continuous measurements of ecophysiological processes contributing to NEE including soil CO_2 efflux, heterotrophic CO_2 efflux, understorey photosynthesis (Liang *et al.* 2003, 2004), overground woody tissue CO_2 efflux (Liang 2003), and canopy photosynthesis.

2.2 Measurement system description

The photosynthesis system has a flow-through, non-steady-state design, comprising 24 automated chambers and a control unit. The control unit is designed as the same as used in soil CO_2 efflux and woody tissue CO_2 efflux systems (Liang *et al.* 2003, 2004), except that channels of the gas sampler have been extended from 16 to 24. In brief, the aluminum control unit (70 × 50 × 35 cm, L × W × H) includes a 24-channel gas sampler, an infrared gas analyzer (IRGA; LI-6262, LI-COR), a datalogger (CR10X, Campbell Scientific) and a compressor system. The cylinder-designed chambers (12 cm in diameter by 30 cm long) are constructed of 0.05 mm high-transmittance polyester film pasted to an acrylic frame. The chamber can completely envelop a segment of

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shoot with several twigs (Liang 2003). Between measurements the two compass-windows, one in each end of the chamber, are opened by two micro air actuators to allow wind to pass through the chamber and prevent temperature increase inside the chamber. During the measurement, the chamber is closed and the chamber air is mixed by a micro fan set inside the chamber. The chamber air is circulated through the IRGA by a micro air pump and the change in CO_2 concentration is measured.

2.3 Field application

At beginning of August 2003, ten trees around a canopy scaffold were sampled for measuring photosynthesis. We set twelve chambers in the sunlit portion of the upper canopy, eight chambers in the mid canopy, and four chambers in the shade portion of the lower canopy. The length of doubled polyurethane tubes used to sample air from each chamber was 20 m. Over the course of an hour, the 24 chambers were sampled in sequence by the 24-channel gas sampler programmed by the CR10X. We set the sampling period for each chamber to 150 s. The CR10X acquired output from the LI-6262 at 1-s intervals and averaged and recorded it every 5 s.

In addition, two photosynthetic photon flux density (PPFD) sensors (G2711, Hamamatsu Photonics) and a thermocouple were installed inside each chamber to monitor light intensity reaching the foliage and air temperature inside the chamber.

3. Results and Discussion

3.1 Weather characteristics

During the measurement period between August 7 and September 6, there were eight rainy days, and total precipitation was 172 mm. On the clear days, air temperature at the canopy height of 14 m usually decreased to about 16 ± 2°C in the night and increased to about 22 ± 1°C in the early afternoon. Averaged volumetric soil moisture was 36%, ranging from 28% to 46%. These indicate that there were no drought and temperature stresses throughout the measurement period for this forest.

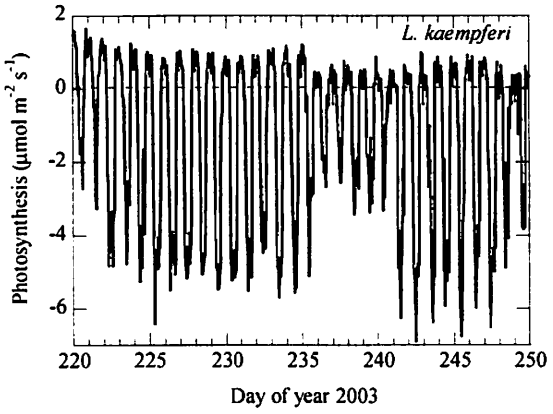

Fig. 1. Diurnal changes of photosynthesis and dark respiration. Data means hourly averaged of 24 chambers.

3.2 Daily changes in photosynthesis and respiration

The hourly mean net photosynthetic rate for the 24 chambers showed significant diurnal patterns with CO_2 absorption during the daytime and CO_2 emission during the nighttime (Fig. 1). Daytime CO_2 absorption was greater on the clear days than that on the cloudy and rainy days. During the one-month measurement, the subjected foliage had net daily CO_2 absorption for all of days, except on August 8 and August 9 (Fig. 3). A strong typhoon with heavy rain came over the canopy on August 8 and August 9; there was only small CO_2 absorption during the daytime but large dark respiration during the nighttime due to high air temperature.

3.3 Light response of canopy photosynthesis

Canopy photosynthesis showed a typical light response curve during the one-month measurement (Fig. 2). Light saturated photosynthetic rate reached to 4.5 + 1.2 μmol m^{-2} s^{-1} that usually occurred with highest irradiances, consisting with LI-6400 (LI-COR) chamber measurement (Liang *et al.*, *under preparation*). Photosynthetic light use efficiency was about 0.021, consisting with previous reports for most tree species.

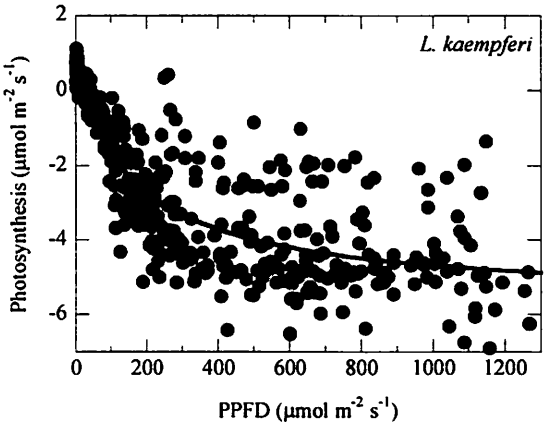

Fig. 2. Light response of photosynthesis in the larch forest canopy. The data points are all of the data for the whole measurement period.

In contrast to LI-6400 chamber measurement, photosynthesis obtained by the automated chambers did not show any late-day depression even on the hot and clear days (Fig. 1), probably suggesting that our automated chambers have no drawback of altering the microclimate around the subjected foliage. Compared to previous chamber results, our result showed high deviation for either photosynthesis during the daytime or dark respiration during the nighttime. High deviation of the result means that the microclimates, such as light intensity, temperature and humidity, inside our automated chamber were not artificially controlled. Moreover, our automated-chamber-based

daily canopy CO_2 absorption showed significant logarithmic correlation with daily irradiance (Fig. 3; Equation 1, $R^2 = 0.83$), consisting with the NEE from the CO_2 flux tower observation (Liang *et al.*, *under preparation*).

$$A = 3.5 - 7.9\log(PPFD) \quad (1)$$

here A is daily CO_2 exchange (gC m^{-2} d^{-1}), $PPFD$ is daily photosynthetic photon flux density (μmol m^{-2} d^{-1}).

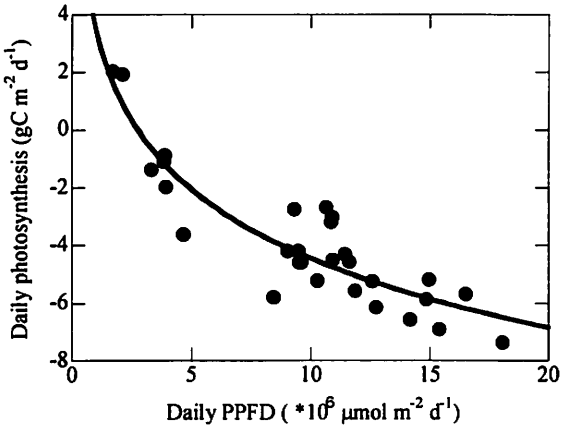

Fig. 3. Relationship between daily CO_2 exchange and daily photosynthetic photon flux density (PPFD).

3.4 Temperature response of dark respiration

The mean nighttime (dark) respiration rate was 0.6 ± 0.4 μmol m^{-2} s^{-1} that was higher during the warmer nights and lower during the cooler nights (Fig. 1), and showed typical exponential correlation with the air temperature (Fig. 4). Q_{10} of the dark respiration is 7.5; the value is significantly higher than previous reports for other tree species by periodical measurements with other chamber systems. Moreover, this Q_{10} of foliage respiration is significantly higher than that of soil CO_2 efflux (3.1) and stem (4.7~5.1) and branch CO_2 efflux (5.5) (Liang *et al.* 2003, 2004), suggesting that foliage respiration is more sensitive to temperature and a small change in air temperature might alter the contribution of foliage respiration to the whole ecosystem respiration.

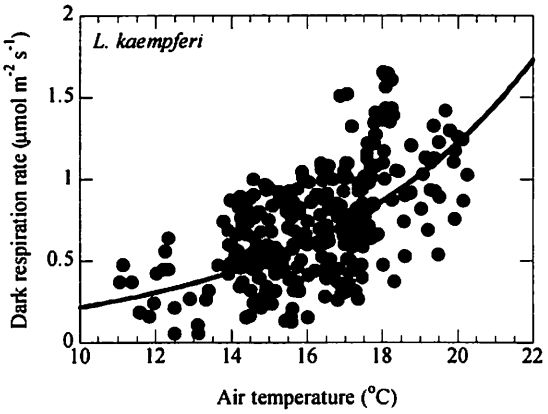

Fig. 4. Temperature response of nighttime (dark) respiration. The data points are all of the data for the whole measurement period.

4. Conclusion

Photosynthesis and nighttime (dark) respiration significantly differ among leaves within the canopy and change with time, and upper-canopy leaves have a much higher maximum photosynthesis and respiration than lower-canopy leaves (Bassow and Bazzaz 1997; Tang *et al.* 2003). It indicates that to obtain representative photosynthetic parameters for an ecosystem, a large numbers of samples and high sample frequency are needed. Our present results and the tower based CO_2 flux indicate that the multichannel automated chamber system presented in this work is effective for continuous measurement of shoot level photosynthesis at different canopy positions with high frequency samples, even on strong windy and rainy days. It can provide a large amount of high-quality data on canopy photosynthesis and dark respiration with foliage surviving in different habitats, i.e. in the fully sunlit portion at upper canopy, in the mid-canopy and in the deeply shaded portion at lower canopy. Coupled with the characteristics of canopy structure, the automated chamber-based data can supply valuable information for scaling up the stand level photosynthesis.

Acknowledgments

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