Variation in Photosynthetic Photon Flux Density on a Larch Forest Floor

Jun-ichi MOGAMI*, Takashi HIRANO*, Ryuichi HIRATA*, Satoshi KITAOKA**,
Takayoshi KOIKE** and Yasumi FUJINUMA***

* Graduate School of Agriculture, Hokkaido University, N9, W9, Kita-ku, Sapporo 060-8589, Japan.

^{**} Field Science Center for Northern Biosphere, Hokkaido University, N11, W10, Kita-ku, Sapporo 060-8511, Japan.

*** National Institute for Environmental Studies, Onogawa, Tsukuba 305-8506, Japan.

Abstract

The field experiment was conducted in a larch forest to investigate temporal and spatial variations in photosynthetic photon flux density (PPFD) on the forest floor (PPFD_f) and the phenological pattern of PPFD_f. PPFD was measured at seven points on the forest floor at height of 1 m and at one point above the canopy (PPFD_c) at 10 Hz from 18 April to 30 September in 2002. PPFD_f was expressed as %PPFD, which is the percentage of PPFD_c. %PPFD decreased as PPFD_c increased and became almost constant over PPFD_c of 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ throughout the measurement period. The relationship was well fitted by a rectangular hyperbola. Temporal and spatial variations in %PPFD increased exponentially with PPFD_c and increased with LAI.

Key words: Forest floor, Larch plantation, Photosynthetic photon flux density (PPFD), Spatial variation, Temporal variation

1. Introduction

It is important to understand light environment below forest canopy, which differs from that above forest canopy, because light intensity on a forest floor plays a major role in the growth of understory vegetation. Light intensity on forest floors is spatially and temporally variable, and the variability of light intensity is influenced by canopy structure and sky conditions (e.g., Anderson, 1970; Gendron *et al.*, 2001). In order to investigate the light variability, we measured photosynthetic photon flux density (PPFD) every 0.1 s at several points on the forest floor of a larch forest for about five months. We show the phenological pattern of the relationship between PPFD measured above the forest canopy (PPFD_c) and on the forest floor (PPFD_f), and temporal and spatial variations in PPFD_f.

2. Materials and Methods

2.1 Site description

The study was conducted in Tomakomai FRS, a Japanese larch plantation (*Larix kaempferi* Sarg.) in Tomakomai, Hokkaido, Japan (42°44'N, 141°31'E). The larch forest was about 45 years old and located on flat terrain. The area of the larch forest was about 100 ha and its canopy height was 15–16 m. In the forest some deciduous broadleaf trees, such as birch (*Betula ermanii* and *Betula platyphylla*) and Japanese elm (*Ulmus japonica*), were scattered. The larch trees foliated in late April and defoliated in November. Leaf area index (LAI) was reached 2.5 m² m⁻² at the

maximum in summer. Hirano *et al.* (2003) described site characteristics in detail.

2.2 Measurement of photosynthetic photon flux density (PPFD)

PPFD was measured with quantum sensors (LI-190A, Licor, USA and PAR-01, PREDE, Japan) at seven points under the canopy at height of 1 m near a 25-m high tower and at one point above the canopy on the top of the tower (Fig. 1). PPFD was recorded with a datalogger (9210, HIOKI, Japan) at 10 Hz from 18 April to 30 September in 2002. The PPFD sensors were calibrated using a new sensor (LI-190A) on the rooftop of a building of Hokkaido University, Sapporo before and after the field experiment. Based on the calibration, data were corrected. In addition, the corrected $PPFD_f$ were converted to $\%PPFD$, which is the percentage of $PPFD_f$ to $PPFD_e$, to eliminate the cloud effect that causes fluctuations in solar radiation.

Fig.1. Distribution of PPFD sensors.

When solar radiation was considerably small, fluctuations in %PPFD was very large because of white noise in the PPFD sensors. Therefore data measured between 0800 and 1600 were only used for analyses. Leaf area index (LAI) was estimated using a plant canopy analyzer (LAI-2000, Licor, USA) and Beer's law (Hirata *et al.*, 2002).

3. Results and Discussion

3.1 Phenological pattern of %PPFD

%PPFD was plotted against $PPFD_c$ on an hourly mean basis every half a month (Fig. 2). %PPFD decreased as $PPFD_c$ increased and became almost constant over $PPFD_c$ of $500 \mu\text{mol m}^{-2} \text{s}^{-1}$ throughout the measurement period. This relationship shows that PPFD transmittance through the canopy was higher at lower $PPFD_c$. When $PPFD_c$ was low in the daytime, it was cloudy and the ratio of diffuse radiation was high in solar radiation.

The relationship between %PPFD and $PPFD_c$ was well fitted by a rectangular hyperbola:

$$\%PPFD = 100 - \frac{a \cdot PPFD_c}{PPFD_c + a/b} \quad (1)$$

Fig. 2. Relationship between %PPFD and $PPFD_c$ on an hourly mean basis for the period of (a) 18–30 April, (b) 16–31 May and (c) 16–30 June. %PPFD is the mean of seven points.

Coefficient a means the sum of absorbed and reflected PPFD by the canopy in percentage at infinite $PPFD_c$. Thus, the residual $c (= 100 - a)$ represents the value of %PPFD at high enough $PPFD_c$. Coefficient b means the rate of %PPFD change when $PPFD_c$ is $0 \mu\text{mol m}^{-2} \text{s}^{-1}$ with a converse sign.

3.2 Temporal variation in %PPFD

A coefficient of variation (CV) of %PPFD was calculated every hour at each point. The mean of CV from seven points (temporal CV) was plotted against $PPFD_c$ to examine temporal variation in %PPFD (Fig. 3). Larger CV represents that variation in %PPFD is larger. In Fig. 3, data were excluded when $PPFD_c$ was below $200 \mu\text{mol m}^{-2} \text{s}^{-1}$ because of large fluctuations in %PPFD. Temporal CV increased exponentially with $PPFD_c$ and increased with LAI. The intercept of the exponential curve increased slightly with LAI, whereas the rate of increase did not change. The increase of the intercept with LAI was probably due to the decrease of %PPFD with LAI (Fig. 2). CV increases as %PPFD decreases even if variation is constant.

Fig. 3. Relationship between temporal CV of %PPFD and $PPFD_c$ on an hourly basis for the period of (a) 18–30 April, (b) 16–31 May and (c) 16–30 June. CV is the mean of seven points.

3.3 Spatial variation in %PPFD

CV of %PPFD was calculated between seven points every 0.1 s and averaged every hour (spatial CV). Figure 4 shows the relationship between spatial CV and $PPFD_c$. Spatial CV increased exponentially with $PPFD_c$ and increased with LAI in the same manner as temporal CV (Fig. 3). This relationship reflects the effect of sunflecks. Difference in $PPFD_f$ between inside and outside sunflecks increases with $PPFD_c$ and LAI. In addition, the intercept of the exponential curve increased with LAI, whereas the rate of increase did not change. The reason for the increase of the intercept with LAI was the same as that for temporal variation.

Fig. 4. Relationship between spatial CV of %PPFD and $PPFD_c$ on an hourly basis for the period of (a) 18–30 April, (b) 16–31 May and (c) 16–30 June.

References

- Anderson, M. C., 1970: Interpreting the fraction of solar radiation available in forest. *Agric. For. Meteorol.*, **7**, 19–28.
- Genrdon, F., Messier, C., and Comeau, P. G., 2001: Temporal variations in the understorey photosynthetic photon flux density of a deciduous stand: the effects of canopy development, solar radiation, and sky conditions. *Agric. For. Meteorol.*, **106**, 23–40.
- Hirano, T., Hirata, R., Fujinuma, Y., Saigusa, N., Yamamoto, S., Harazono, Y., Takada, M., Inukai, K., and Inoue, G., 2003: CO₂ and water vapor exchange of a larch forest in northern Japan. *Tellus*, **55B**, 244–257.
- Hirata, R., Sugimoto, K., Hirano, T., Koike, T., Kitaoka, S., Yuzu, T., Fujita, R., Fujinuma, Y., Takada, M. and Inukai K., 2002: Seasonal variations in leaf area index and radiation environment of a larch forest. *Agric. Meteorol. Hokkaido*, **54**, 53–62 (in Japanese).