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Seasonal and interannual variations in carbon dioxide exchange of a temperate larch forest

Ryuichi Hirata [a,*], Takashi Hirano [b], Nobuko Saigusa [c], Yasumi Fujinuma [a], Koh Inukai [a], Yasuyuki Kitamori [d], Yoshiyuki Takahashi [a], Susumu Yamamoto [e]

[a] *Center for Global Environmental Research, National Institute for Environmental Studies, 16-2, Onogawa, Tsukuba, Ibaraki 305-8506, Japan*

[b] *Graduate School of Agriculture, Hokkaido University, Japan*

[c] *National Institute of Advanced Industrial Science and Technology, Japan*

[d] *Institute of Low Temperature Science, Hokkaido University, Japan*

[e] *Graduate School of Environmental Science, Okayama University, Japan*

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Abstract

This paper reports 3-year measurements (2001–2003) of the net ecosystem CO_2 exchange (NEE) over a northern Japan larch plantation forest, using an eddy covariance technique with both open- and closed-path systems. The study evaluates interannual variations in the seasonal patterns of NEE, the annual NEE, clarifying the factors controlling the carbon balance. NEE for both open- and closed-path systems look equivalent from the half-hourly mean values; however, there is a small systematic bias in the annual cumulative totals. In this study, we used closed-path data because open-path data during winter are doubtful and the annual NEE from closed-path data was closer to the biometric NEP than that from open-path data.

The 3-year averages of annual NEE, gross primary production (GPP), and ecosystem respiration (RE) were -212 ± 43 (standard deviation), -1673 ± 59, and 1462 ± 42 gC m^{-2} y^{-1}, respectively. The larch plantation forest absorbed large amounts of CO_2 during just 1 month, June. During that period, photosynthetic photon flux density (PPFD) was large while the temperature was not high. These meteorological conditions were suitable for CO_2 absorption before the leaf area index (LAI) reached its peak. Maximum GPP at light saturation (P_{max}) was also large. During the 3-year measurement period, PPFD in summer, and temperatures in spring and summer engendered remarkable interannual differences of GPP, RE, and NEE. In spring, snowmelt and larch foliation occurred about 2 weeks earlier in 2002 than in either 2001 or 2003 because of higher temperatures; consequently, the ecosystem began to photosynthesize earlier. In July, NEE was more negative in 2003 than in other years. The GPP became larger because of higher PPFD, larger P_{max}; while the RE became smaller because of lower temperatures.

Compared with similar forests, the amounts of GPP and RE measured here were large, but NEE was similar. The reason is that the photosynthetic capacity of larch is naturally large: the ample PPFD, and the lack of environmental stresses from dry air or soil, consequently allows high photosynthesis rates to be maintained. Moreover, it can be inferred that RE values are enhanced by the high photosynthetic activity of larch forest during the growing season.

Keywords: Larch forest; Eddy covariance; Net ecosystem CO_2 exchange (NEE); Gross primary production (GPP); Ecosystem respiration (RE)

1. Introduction

Long-term observations of CO_2 flux from a tower using the eddy covariance technique are useful for

* Corresponding author. Tel.: +81 29 706 4144; fax: +81 29 850 2960.

E-mail address: hirata.ryuichi@nies.go.jp (R. Hirata).

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elucidating the carbon balance of terrestrial ecosystems (Valentini et al., 2000; Baldocchi et al., 2001). An important objective of long-term observations is to elucidate interactions among terrestrial ecosystems and climate to predict net ecosystem CO_2 exchange (NEE) and any causes of interannual variations. Therefore, long-term observations of the exchange of carbon dioxide, water vapor, and heat have been performed for various terrestrial ecosystems (Baldocchi et al., 2001). However, reports that address NEE for Asian ecosystems, which are climatically affected by Asian monsoons, are limited (Yamamoto et al., 1999; Saigusa et al., 2002; Hirano et al., 2003; Nakai et al., 2003) compared with those addressing ecosystems in Europe and North America.

Japanese larch (*Larix kaempferi*) were planted intensively throughout northern Japan after World War II because of their high cold tolerance and high timber productivity. Especially on Hokkaido Island, which has an area of 78,000 km^2, larch forests have become an important forestry resource. Such forests cover 4700 km^2, accounting for one-third of Hokkaido's total forest area (Fujinuma et al., 2001). Despite the importance of larch plantation forests, few studies have examined their carbon balance. Since September 2000, long-term measurements of CO_2, water vapor, and sensible heat fluxes have been made using the eddy covariance technique above a larch plantation forest in Hokkaido, Japan; Hirano et al. (2003) and Wang et al. (2004) reported their measurement methods and initial analyses. The present paper reports measurements of CO_2 flux for the 3 years of 2001–2003. This paper evaluates the interannual variations in (1) the seasonal patterns of NEE and (2) those of annual NEE, and (3) clarifies the characteristics of larch plantation forests for use in carbon balance calculations.

2. Materials and methods

2.1. Site description

The study site (42°44′N, 141°31′E; elevation 140 m) is a cultivated *L. kaempferi* forest in the Tomakomai National Forest, managed by the Hokkaido Regional Office of the Forestry Agency. It is located 10 km east of a volcano, Mt. Tarumae, which erupted about 300 years ago, and is approximately 15 km northwest of Tomakomai, Hokkaido, in northern Japan. The terrain of this site is almost flat, with a slope of 1–2° (Fig. 1). The trees were about 45 years old at the time of this study. The larch forest area is about 100 ha. A 42-m tower was built near the forest center to measure fluxes

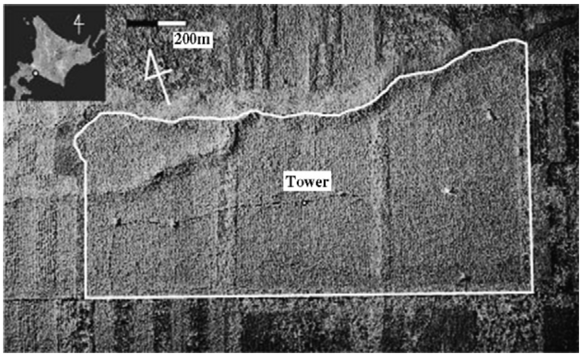

Fig. 1. Photo of the study area.

and for meteorology data collection. The fetch was between 300 m to the north and 800 m to the west and east, while it was about 400 m for the south, which was the dominant wind direction. The stand of larch is surrounded by deciduous broadleaf and evergreen conifer forests. The canopy height at the time of the study was approximately 15 m. The forest includes scattered deciduous broadleaf trees (*Betula ermanii*, *Betula platyphylla*, and *Ulmus japonica*) and sparsely distributed spruce (*Picea jezoensis*). The stand densities of trees with diameters at breast height (DBH, 1.3 m) larger than 5 cm were 673, 459, 18, and 1150 stems ha^{-1}, respectively, for larch, broadleaf trees, spruce, and all species in 1999 (Hirano et al., 2003). The basal area DBHs of larch, broadleaf trees, spruce, and all species were, respectively, 19.0, 4.1, 0.4, and 23.5 m^2 ha^{-1}. Therefore, larch trees accounted for 81% of all species on a stem-area basis, but for 59% on a stem-number basis. The maximum leaf area index (LAI) of larch, other overstory species, and all overstory species (LAI_O) were about 3.1, 2.5, and 5.6 m^2 m^{-2} in summer, respectively. The respective above-ground, below-ground, and total carbon stocks of larch trees were 33.9 and 42 t ha^{-1} in 2001 (Matsuura, personal communication). The average larch tree height increased about 0.3 m y^{-1} during 1999–2002 (Yuzu, personal communication).

The forest floor was thickly covered with understory species that mainly consist of fern (*Dryopteris crassirhizoma* and *Dryopteris austriaca*) and *Pachysandra terminalis*. Floor vegetation had a maximum height of 0.9–1.4 m and maximum LAI (LAI_U) of 3.6 m^2 m^{-2} in July. The above-ground dry matter of the understory was about 27 t ha^{-1} in June and July 2001 (Yuzu et al., 2003). The total LAI of the overstory and understory was about 9.2 m^2 m^{-2} in the summer period. The soil is a volcanogenous regosol with 1–2-cm thick fresh litter and a 5–10-cm thick decomposed organic