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Temporal and Spatial Variations in CO_2 Concentration within a Japanese Cedar Forest on a Slope Land

Mariko NORISADA*, Takeshi TANGE*, Makoto SUZUKI** and Satohiko SASAKI*, ***

Introduction

Carbon dioxide (CO_2) concentrations within a forest are the results from source-sink relations involving the transportation process of CO_2 in the forest. Respirations of vegetation and soil respirations play as sources of CO_2. On the other hand, the photosynthesis of vegetation plays as the sink of CO_2. The atmosphere above the canopy plays as sources in daytime and as sinks in nighttime. The diffusion and the winds are the transportation process of CO_2. The stratification of CO_2 concentrations resulting from this sink-source relation have been reported by earlier workers (e.g. GARRET *et al.*, 1978; BAZZAZ *et al.*, 1991). However, most of these studies were done within the forests on the flat land and those data on slope-land forest are rare.

The object of the present study is to determine the temporal and spatial variations in CO_2 concentrations within a forest on a slope land, which is common in forest area in Japan, and examine its relationships with photosynthetic rates. In addition, environmental conditions such as light intensity, air temperature, air humidity, wind velocity and wind direction were measured to examine their effects on the CO_2 concentrations.

Study Site

The study site was a 27-year-old Japanese cedar (*Cryptomeria japonica* D. Don) man-made forest, about 15 m tall, in the Tokyo University Forest in Chiba. The University forest is located in the south-east part of Boso Peninsula in Kanto Area, Japan. The study site is about 70 km away from Tokyo and about 5 km from the coast line of the Pacific Ocean. According to meteorological data available at a station 2.5 km from the site, annual mean air temperature and precipitation are 14℃ and 2300 mm, respectively (The Tokyo University Forest in Chiba, 1987; The University Forests, Faculty of Agriculture, The University of Tokyo, 1992a, 1992b, 1993, 1994, 1995, 1996). The stand was surrounded by north-, south-, and east-facing steep slopes. The difference in altitude between the highest ridge and the bottom is about 28 m. Understory vegetation is rare. A 20 m tall measurement tower was made on the middle part of the east-facing slope.

Methods

The measurement points were established at four different heights along the tower. The four measurement points were located near the forest floor, in the lower canopy, in the upper canopy, and above the canopy, respectively. The heights of the measurement points were 0.6, 9.6, 14.3, and 19.6 m above the ground, respectively. At each point, an air-sampling tube, a quantum sensor (IKS-25, Koito Kogyo Co., Ltd.) and a Pt100 Ω resistance thermometers (NR, Chino) were set up. The sample air at each point was drawn through a

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vinyl chloride tube toward an infrared gas analyzer (IRGA; ZAR model, Fuji Electric Co., Ltd.) and a dew point meter (model 911, EG&G) by each of four air pumps. The IRGA was calibrated periodically with standard gases of 500 and 900 ppm CO_2 concentration using nonlinear regression. The wind velocity and direction was measured on the top of the tower with three anemometers (No. 550, Ota Keiki Seisakusho) located in three dimensions. These measurements were done from 18 June to 31 December, 1991. Each data were logged in a personal computer for each 1 to 8 minutes.

To examine the effects of photosynthetic rates on CO_2 concentration, crown photosynthetic rates were measured with ventilated crown-chamber methods from 13 September to 7 October, 1993. Another measurement tower had been made by earlier researchers to surround a Japanese cedar near the CO_2 measurement tower. The crown of the Japanese cedar were enclosed with vinyl chloride sheet and ventilated with a fan at the bottom of the chamber, which hung from the beam of the tower. Carbon dioxide concentration of the inlet and outlet air were measured as well as those at four measurement points along the CO_2 measurement tower. The data were logged in a personal computer. Crown photosynthetic rate was determined by air flow velocity and CO_2 concentration gradients between inlet and outlet air of the chamber.

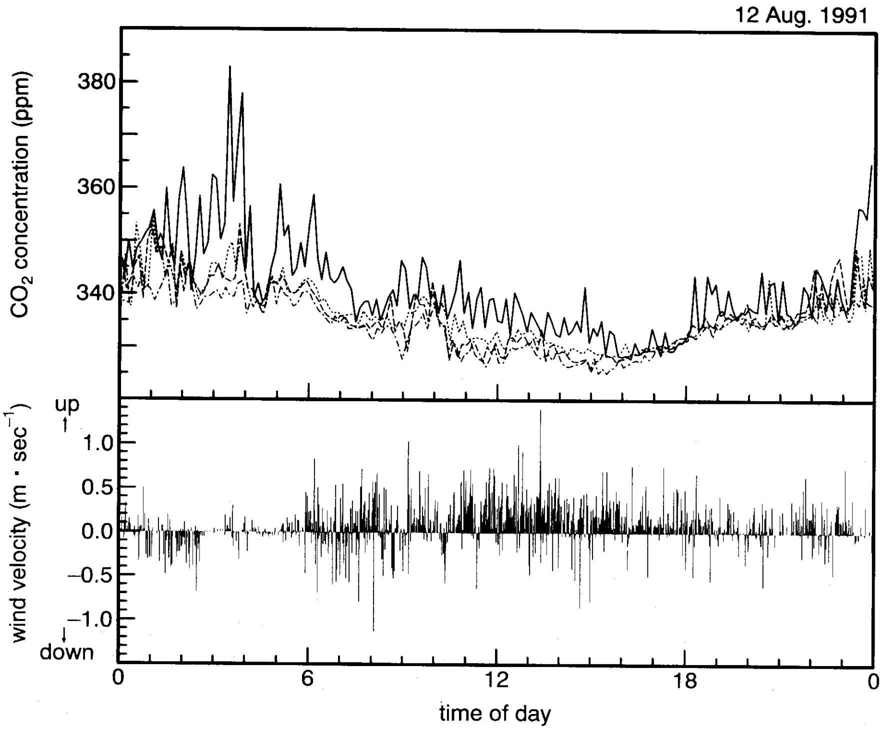

Fig. 1. Diurnal fluctuations of CO_2 concentrations at four heights within a Japanese cedar forest. Solid line; near the forest floor, dotted line; in the lower canopy, dashed line; in the upper canopy, dot dashed line; above the canopy. Vertical wind velocity measured above the canopy were shown in the lower panel.

Results and Discussion

Vertical Variations of CO_2 Concentration

The diurnal fluctuation of vertical variations in CO_2 concentrations was shown in Fig. 1. Excepting for the concentration near the forest floor, the differences of CO_2 concentrations among the different heights were less than 3 ppm. This little gradients of the CO_2 profile makes a contrast to the strong stratification of CO_2 concentrations in daytime within flat forests reported by earlier workers (GARRET *et al.*, 1978; BAZZAZ and WILLIAMS, 1991).

With such slope topography in the study stand, wind is likely to blow along the slopes so that the vertical winds blow regularly. These vertical winds may disturb the development of the stratification of CO_2 concentrations.

When the vertical wind velocity was very low, the CO_2 concentrations near the forest floor became much higher than those at the upper measurement points. The differences of CO_2 concentrations among the upper three measurement points were little even under such conditions (Fig. 1).

If the vertical wind velocity is low, the CO_2 released through the soil respiration could be accumulated near the forest floor, resulting in high CO_2 concentrations near the forest floor. SPARLING and ALT (1965) reported similar wind effects on CO_2 concentration. Low diffusion resistance could be a cause of small stratification within canopy under such low wind velocity. The needle leaves of Japanese cedar are very small so that the diffusion resistance between the leaf surface and the bulk air may be small (WHITEHEAD and JARVIS, 1981). This small diffusion resistance can bring enough diffusion of CO_2 within the canopy under low wind velocity. This might have led to the little differences of CO_2 concentrations among the upper three measurements points even if the winds blow very slow. As another possibility, the canopy density of the study stand might be low enough to bring high diffusion rate through the canopy.

Diurnal Course in CO_2 Concentration

The typical diurnal courses of CO_2 concentrations on fine days in summer were shown in Fig. 2. Carbon dioxide concentration at all measurement points showed the similar diurnal course, with larger fluctuations near the forest floor. During the nighttime, the CO_2 concentrations were almost constant. After daybreak, the CO_2 concentrations dropped rapidly as the light intensity increased. When the light intensity reached to about 600 $\mu mol \cdot m^{-2} \cdot sec^{-1}$, the CO_2 concentrations turned to be constant. When the light intensity got lower than 600 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ again, the CO_2 concentrations increased steadily up to the nighttime level along with the decrease of light intensity.

The relatively larger fluctuation in CO_2 concentration near the forest floor than those at upper three measurement points may show the influence of CO_2 emission from the soil. The smaller fluctuation at the upper three measurement points indicate higher diffusion rates within and above the canopy than those under the canopy, which could result in stronger influence of surrounding air above the canopy than those from the soil surface.

Photosynthetic Effects on CO_2 concentration

A strong relationship was found between CO_2 concentration and crown photosynthetic rate (Fig. 3). The CO_2 concentration decreased with diminishing its rates as the photosynthetic rates increased, followed by rather constant value under photosynthetic rates higher than 40 $mol \cdot sec^{-1} \cdot tree^{-1}$. The result shows that the CO_2 concentration within the forest is strongly determined by the canopy photosynthetic rates. The diminished rate of CO_2 concentration decrease along with the photosynthetic rate increase might have resulted

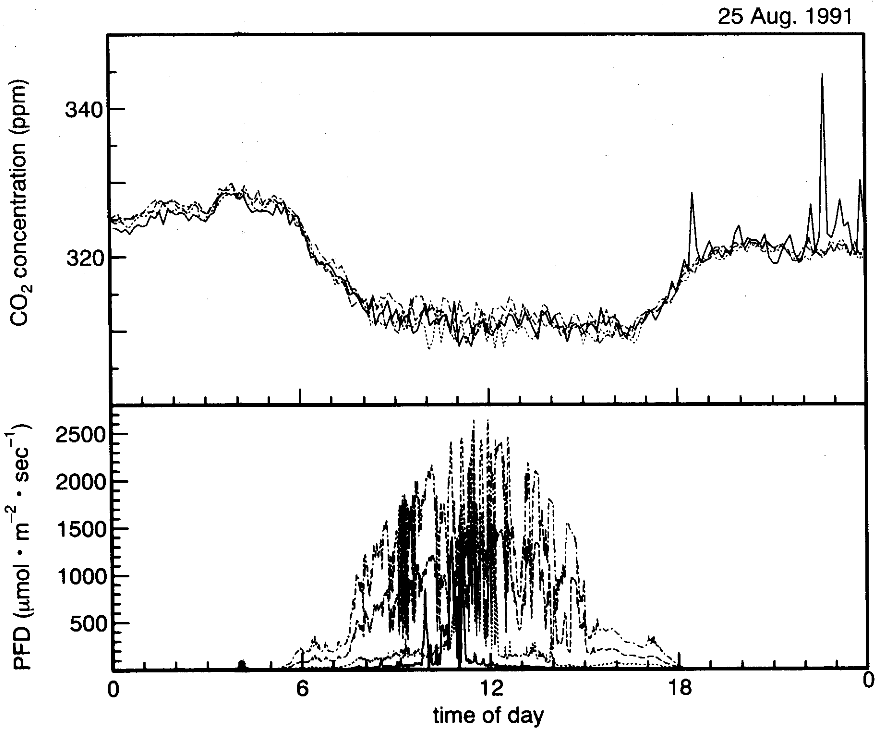

Fig. 2. Typical diurnal courses of CO_2 concentrations at four heights within a Japanese cedar forest on fair days in summer. Solid line; near the forest floor, dotted line; in the lower canopy, dashed line; in the upper canopy, dot dashed line; above the canopy. Photon flux density (PFD) at four heights are shown in the lower panel.

from the increased diffusion rates caused by the increased CO_2 gradient between just above the canopy and the upper atmosphere, which was not determined in the present study.

Environmental Effects on CO_2 Concentration

Since the present study site showed a strong influence of canopy photosynthesis on the CO_2 concentration, a strong relationship between light intensity and CO_2 concentration could be expected. In order to clarify the relationship between light intensity and CO_2 concentrations, the relationship between the mean light intensity during one hour prior to the each measurement time and the daytime decrease of the CO_2 concentrations from the daily nighttime level was examined. Daily nighttime level of CO_2 concentrations was determined from the mean of CO_2 concentration during the nighttime, defined as the time before daybreak and after sunset in a day. The decrease of CO_2 concentration from the daily nighttime level (DCN) was calculated with subtraction of CO_2 concentrations in daytime from the daily nighttime CO_2 concentration level.

The relationship between light intensity and the DCN showed the feature of a rectangular hyperbola (Fig. 4). Under light intensity lower than 600 μmol·m^{-2}·sec^{-1}, the DCN increased along with light intensity increase. When the light intensity exceeded 600 μmol·m^{-2}·sec^{-1}, the DCN reached to a plateau. These relationships were found on cloudy or rainy days as well as on fair days. This relationship was similar to the relationship between light intensity and the crown photosynthetic rate measured with the crown-chamber

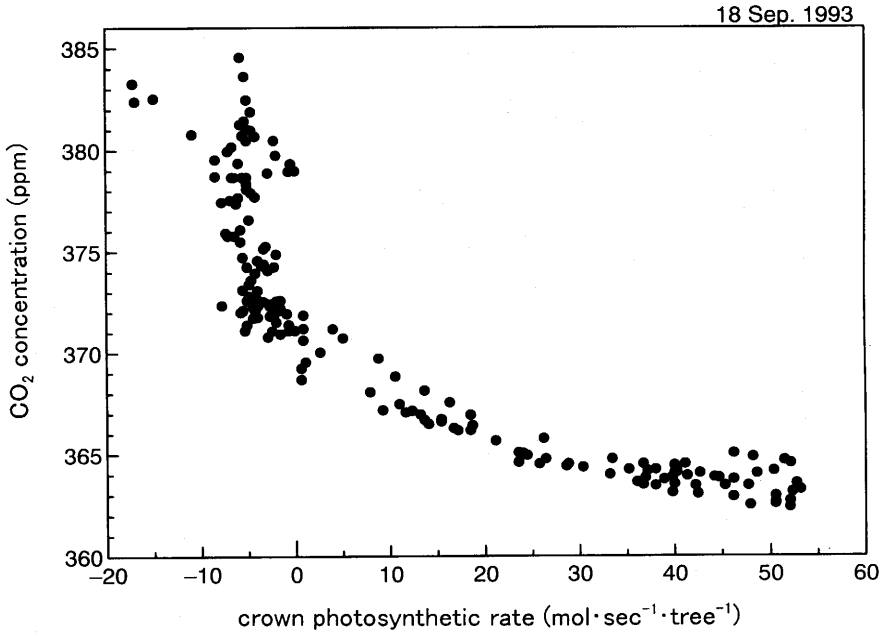

Fig. 3. Photosynthetic effects on CO_2 concentration within a Japanese cedar forest. Crown photosynthetic rates were measured with the crown chamber method.

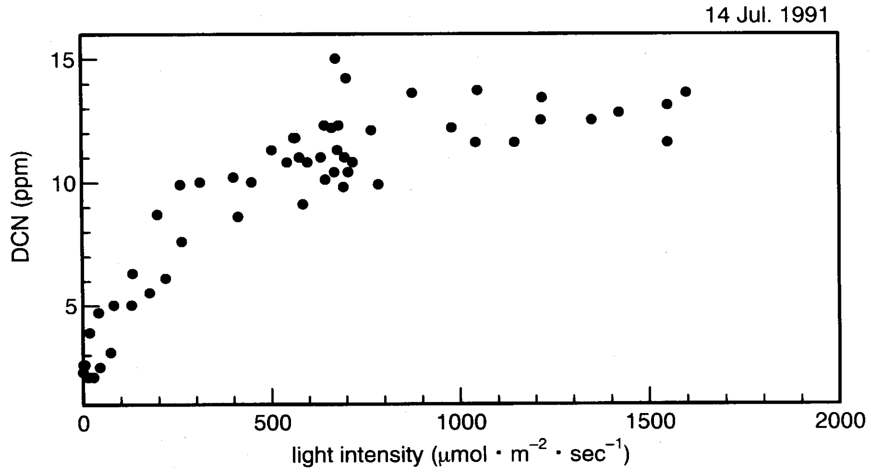

Fig. 4. The relationship between light intensity and daytime CO_2 concentration decrease from the daily nighttime level (DCN). Light intensity was given as the mean photon flux density for each one hour prior to the each CO_2 measurement time.

methods. Shirahata *et al.* (1989) also reported the same relationships on a crown and on a sunny-leaf of a Japanese cedar in the same study site. This similarity is the result from the strong relationship between CO_2 concentration and canopy photosynthetic rate. As far as the light intensity is lower than the light saturation point of canopy photosynthesis, the CO_2 concentrations decrease along with light intensity increase, which results from photosynthesis increase. After light intensity exceeds the light saturation point, the canopy photosynthetic rate turns to be constant, resulting in the stable CO_2 concentrations.

The daily maximum DCN on fair days in summer varied between 10 to 15 ppm. No effect of winds was found on the variance of daily maximum DCN. When the daily maximum water vapor pressure deficit was higher than 1.0 kPa, the daily maximum DCN tended to be smaller. However, this tendency was too weak to consider that the smaller maximum DCN are the results from the depressed photosynthetic rate caused by water stress under high water vapor pressure deficit.

In winter, if the air temperature was higher than 10℃, the CO_2 concentrations decreased during daytime as in summer (Fig. 5). The DCN reached to 5 ppm at the maximum. However, when the air temperature were lower than 10℃ during the day, the CO_2 concentrations were mostly constant throughout the day (Fig. 5). This indicates that air temperature can be a major factor influencing CO_2 concentration in winter, by suppressing the canopy photosynthetic rate under low air temperature.

Sometimes the CO_2 concentrations at all heights simultaneously rose more than 50 ppm higher within one hour and immediately dropped to the level before (Fig. 6). Those

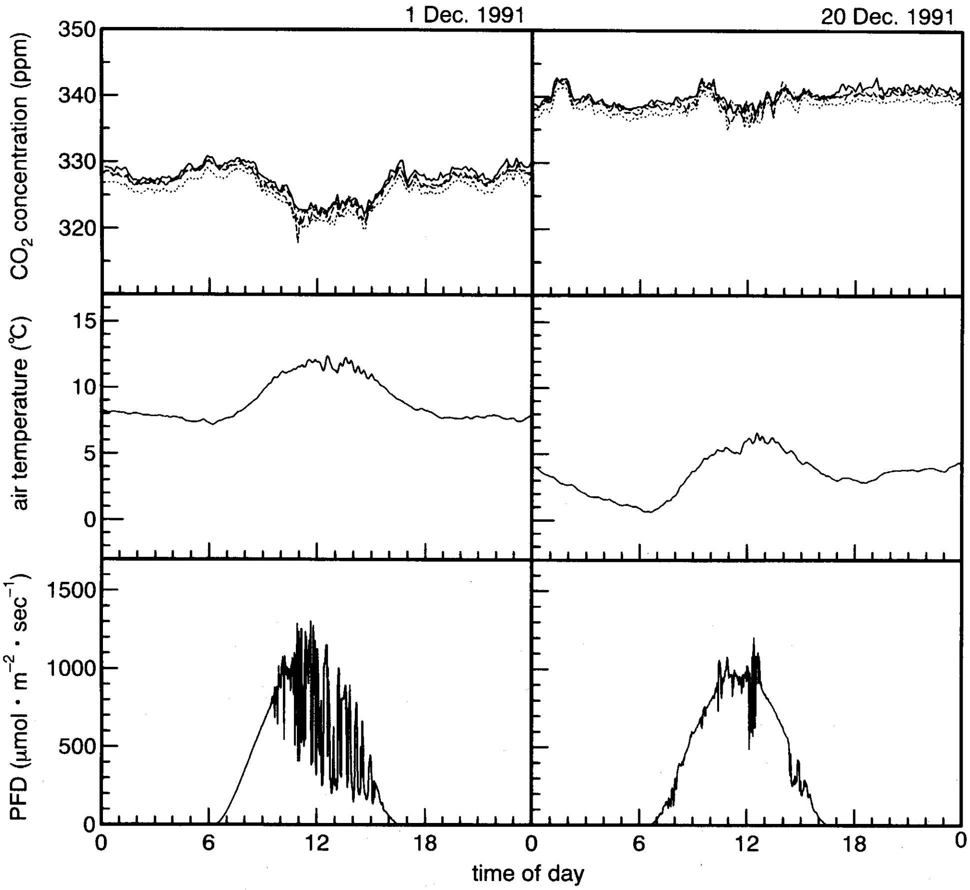

Fig. 5. Temperature effects on CO_2 concentrations within a Japanese cedar forest in winter. Top panels; CO_2 concentration, solid line; near the forest floor, dotted line; in the lower canopy, dashed line; in the upper canopy, dot dashed line; above the canopy. Middle panels; air temperature. Bottom panels; photon flux density (PFD) above the canopy.

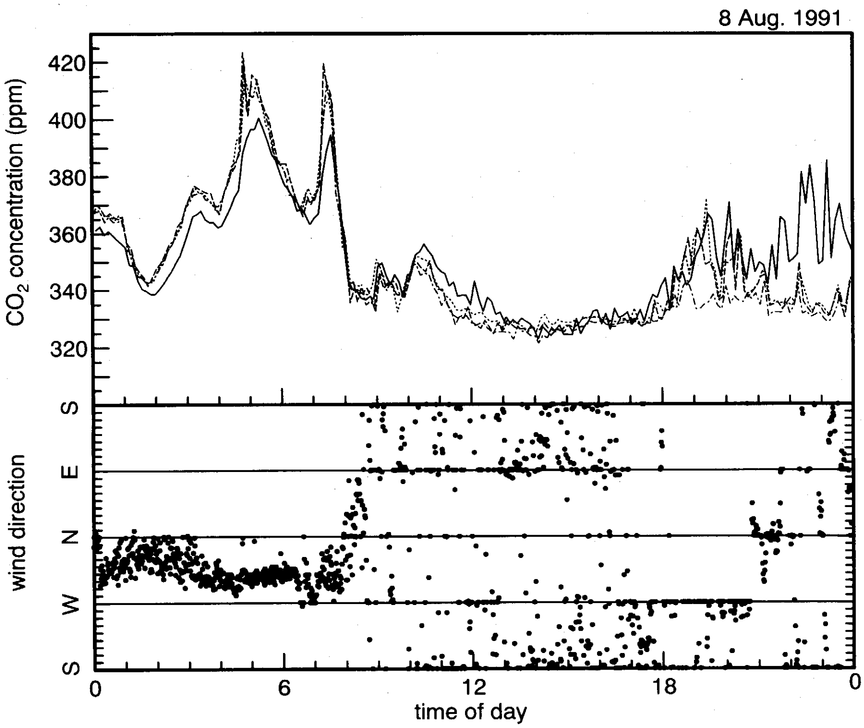

Fig. 6. Wind direction effects on CO_2 concentrations within a Japanese cedar forest. Solid line; near the forest floor, dotted line; in the lower canopy, dashed line; in the upper canopy, dot dashed line; above the canopy. Wind direction measured above the canopy were shown in the lower panel.

rapid changes at all heights occurred when the winds blew from the northwest direction. Considering that the urban area stretches out in the northwest from the study site, and that the CO_2 concentrations in urban area are about 50 ppm higher than those in the study stand (SAOTOME *et al.*, 1992), the rapid changes might indicate the effects of the inflow of CO_2 enriched air from urban area. Those rapid changes occurred more often in nighttime than in daytime. In daytime, forest canopy could be the sink of CO_2 through photosynthesis, which might diminish the effect of the inflow of the CO_2 enriched air.

In the present study, it has been clarified that the CO_2 concentrations within a Japanese cedar forest on a slope land normally show no stratification, and that the CO_2 concentrations are strongly determined by canopy photosynthetic rates, which results in the strong relationships between CO_2 concentration and light intensity. Wind velocity and direction sometimes are other major factors which influence the CO_2 concentration.

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Summary

Atmospheric carbon dioxide concentrations within a Japanese cedar (*Cryptomeria japonica* D. Don) manmade forest on a slope land were continuously measured at four sampling points, above the canopy, in the upper canopy, in the lower canopy and near the forest floor. Air humidity, light intensity, air temperature, wind velocity and wind direction were measured simultaneously. The stratification of CO_2 concentrations, which has been reported by earlier researchers within the flat forests, was generally not clear. However, when the vertical wind speed was low, the CO_2 concentrations near the forest floor were more than 60 ppm higher than those at the other measurement points. During fine weather in summer, the CO_2 concentrations at all measurement points were stable during the nighttime and dropped after daybreak to a stable level during the middle of the day, followed by an increase up to the nighttime level before sunset. The CO_2 concentration was strongly affected by the crown photosynthetic rates of Japanese cedar. The decrease of CO_2 concentrations in daytime from the nighttime level extended as the light intensity increased. However, if the light intensity exceeded $600\,\mu mol \cdot m^{-2} \cdot sec^{-1}$, the decrease of CO_2 concentrations from the nighttime level was constant. This relationship between light intensity and daytime CO_2 concentrations decrease was similar to that between the light intensity and the crown photosynthetic rate of Japanese cedar. When the wind blew from the northwest, the CO_2 concentrations at all heights rose and dropped in short time. This might indicate the influence of CO_2 enriched air inflow from the urban area.

Key words: CO_2 concentrations, Slope land, Crown photosynthetic rate, Light intensity, Wind

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斜面上のスギ林内における二酸化炭素濃度の時空間的変動

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要　旨

スギ人工林内において二酸化炭素濃度を継続測定した。林冠上，林冠上部，林冠下部，林床近くの計４点に測定個所を設けた。大気湿度および光強度，気温，風速，風向を併せて測定した。これまでに報告されているような林内での二酸化炭素濃度の階層化は明瞭ではなかった。しかしながら，垂直方向の風速が弱いときには，林床近くの二酸化炭素濃度が他の３点よりも 60 ppm 以上高くなることがあった。４点ともに夏季の晴天日には，夜間は二酸化炭素濃度が安定しており，日の出後に濃度が下がり始め，やがて安定し，日の入り前に再び上昇するという日変化をした。二酸化炭素濃度はスギの樹冠光合成速度の影響を強く受けていた。光強度が強いほど日中の二酸化炭素濃度の低下量が大きかったが，光強度が 600 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ 以上になると低下量が安定した。この関係はスギの光―樹冠光合成曲線に類似していた。北西から風が吹くと二酸化炭素濃度が急激に上昇することがあり，高濃度の二酸化炭素を含む都市部の空気の移流が示唆された。

キーワード： 二酸化炭素濃度，斜面，樹冠光合成速度，光強度，風

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Atmospheric carbon dioxide concentrations within a Japanese cedar (*Cryptomeria japonica* D. Don) manmade forest on a slope land were continuously measured at four heights. The stratification of CO_2 concentrations, which has been reported by earlier workers, was generally not clear. The CO_2 concentration was strongly affected by canopy photosynthetic rates, resulting in strong relationships between CO_2 concentration and light intensity. Wind velocity and wind direction were sometimes other major factors influencing the CO_2 condition.

The Distribution Pattern of *Semanotus japonicus* (Coleoptera, Cerambycidae) in an Old Plantation of *Cryptomeria japonica* and *Chamaecyparis obtusa* in the Southern Part of Boso Peninsula, Chiba, Japan

Kenji NAKAJIMA and Kôhei KUBOTA

Infestation marks (adult emergence holes and larval galleries) of the sugi bark borer (*Semanotus japonicus*) were investigated in a 72 year old plantation of Japanese cedar and Japanese cypress in the Tokyo University Forest in Chiba. They showed a contagious distribution pattern and most of them were near the ground and at about 10 m in height. Newer infestation marks tended to occur at the cicatrices caused by the past infestation. The cicatrix may provide a suitable condition for larvae. Some trees in an old forest may become a source of the beetles which disperse to young plantations.