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An apparatus for determining the CO_2 gas-exchange of a forest tree in the field

Akio HAGIHARA※, Kazuo HOZUMI※ and Shigeru HANDA※※

野外において林木個体の二酸化炭素収支を計測するための装置

萩原　秋男※　穂積　和夫※　半田　繁※※

An apparatus for continuous measurement of CO_2 gas-exchange in regard to a whole forest tree in the field is described. The CO_2 gas-exchange rate is determined in an open system by an infra-red gas analyser. The air temperature inside an assimilation chamber can either automatically track ambient air temperature or be held at constant set points. The measuring system is controlled by a microcomputer according to predetermined set points. All data in the continuously operating gas-exchange system are successively monitored by devices such as the CRT-display and analog recorder. The microcomputer can also acquire a large amount of data for subsequent computer analysis. This apparatus has been used successfully for a forest tree of *Chamaecyparis obtusa* (Siebold & Zucc.) Endl.

野外において，立木状態にある林木個体の二酸化炭素収支を，連続的に長期間に渡り測定するための装置を組み立てた。この装置は，基本的には開放系の二酸化炭素計測システムである。透明のポリ塩化ビニルフィルムでできた同化箱内の温度を，空気冷却装置により外気温に正確に同調させることができ，また任意の設定温度にも保つことができる。空気溜を設けることにより，安定したCO_2濃度の外気が同化箱に導入される。計測システムは，マイクロコンピュータにより制御され，CO_2濃度，日射量，温度などのデータは，フロッピーディスクに収録される。この計測システムを11年生ヒノキ林木個体に適用し，満足のいく結果を得ることができた。

Key words: *Chamaecyparis obtusa*, Continuous measurement, CO_2 gas-exchange, Field conditions, Whole forest tree.

1. Introduction

Information about photosynthetic production by individual trees of a forest is very fragmentary (Hagihara and Hozumi 1986). An apparatus for measuring the CO_2 gas-exchange of a whole forest tree can be regarded as an effective means for understanding the way in which crown photosynthesis is integrated into total canopy photosynthesis.

In order to determine the CO_2 gas-exchange of plants it is usually necessary to enclose the sample in a transparent assimilation chamber. When the chamber is built in the field, the greenhouse effect causes severe overheating inside the chamber. The methodology to avoid this overheating has been summarized in detail by Jarvis et al.

※ 名古屋大学農学部 School of Agriculture, Nagoya University, Chikusa-ku, Nagoya 464
※※ 小糸工業環境調節技術部 Environmental Control Division, Koito Industries, Limited, Maeda-cho, Totsuka-ku, Yokohama, 244

(1971), Schulze and Koch (1971), and Mooney (1972).

The work of Lange et al. (1969) has stimulated to build more efficient gas analysis equipments that can track ambient air temperature and humidity (Moony et al. 1971, Martin et al. 1974, Linder et al. 1980, Maruyama 1980, Kakubari et al. 1985). These kinds of equipments have been developed to be relatively small chambers, as they measure directly in the field the gas-exchange of attached leaves, shoots, or seedlings (cf. Louwerse and Eikhoudt 1975, Kumura et al. 1978). For the purpose of obtaining information on the CO_2 gas-exchange of one whole forest tree, it is inevitable for the chamber to become larger in volume, which consequently makes it more difficult to control the climate inside the chamber.

Recently Matsumoto (1985) has attempted to measure the CO_2 gas-exchange of a whole forest tree of *Cryptomeria japonica*. In his measurement the overheating inside an assimilation chamber could be avoided by the use of faster flow rates of air through the chamber (Tranquillini 1964). However, the use of very high flow rate may lead to decrease precision in measurements because of reduction in differential CO_2 content between the air entering and leaving the chamber. Therefore, it may be necessary to use a chamber with a temperature control system (Musgrave and Moss 1961, Hotta and Takeuchi 1974, Tsuno and Hirayama 1978).

We developed a new assembly for regular and continuous measurement of the CO_2 gas-exchange of an individual forest tree in as natural field conditions as possible. We introduce the assembly with its application to a forest tree of *Chamaecyparis obtusa* (Siebold & Zucc.) Endl.

2. Experimental installation

As depicted in Fig. 1, the installation is an open system for determining the CO_2 gas-exchange of a forest tree in field conditions. The system is composed of the following five units of components.

i. Assimilation chamber unit

The aboveground part of a forest tree is enclosed by an assimilation chamber of 4.5 m in height and 1m in diameter. The chamber is cylindrical, excepting the conical upper part whose top end is cut off to draw of the inside air. The chamber is made of polyvinyl chloride films (Takafuji Chem. & Syn. Co., Ltd.) 0.2 mm thick with a transmissivity of ca. 90% of photosynthetically active radiation. The skirt of the chamber is tied around the base of the stem. The chamber is supported by steel frames, which can be easily removed to chambers of other trees.

ii. Temperature control unit

Air temperatures are detected both outside and inside the chamber by platinum resistance thermometers. When the inside temperature is higher than outside temperature, a temperature controller (MC-D3KW ; Koito Ind., Ltd.) can adjust the inside temperature to match the outside temperature according to a PID control system (Fig. 2). This feedback control is obtained by adjusting the amount of running water through a fan convector with a system of a solenoid 3-way valve. The water in a tank of 0.8 m^3 is chilled by a water cooler (RKS-400S-B; Orion Mach. Co., Ltd.). The cooling ability of 880 kcal h^{-1} achieves a temperature of 10 degrees below the outside temperature under full solar radiation. An additional temperature control mode is installed in the unit for the purpose of maintaining the inside temperature at some fixed levels.

iii. Incoming air control unit

Air is introduced into the bottom of the chamber by a ventilating fan (VFC304P; Fuji Elect. Co.,

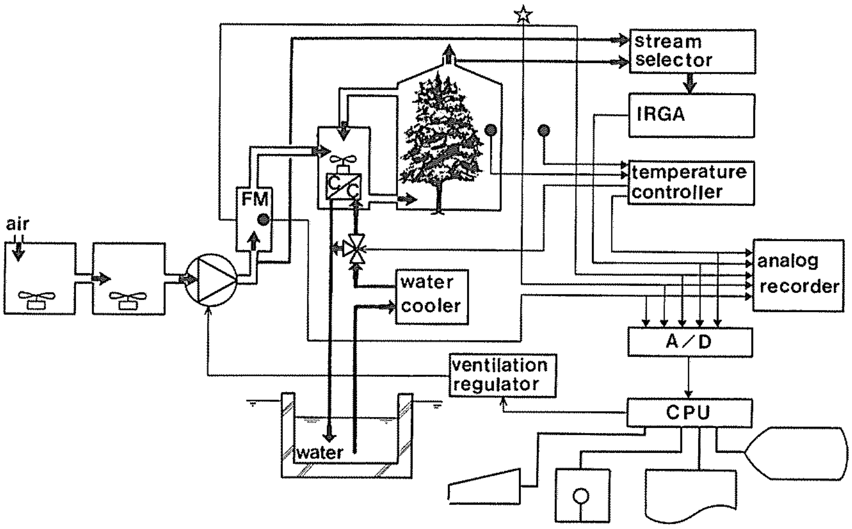

Fig. 1. Schematic diagram of the experimental apparatus. FM : flow meter, C/C : heat exchanger, ⦿: ventilating fan, ⧖: solenoid 3-way valve. ☆: photometric sensor, ●: thermometer, →: measure lead, →: control lead, ➔: air guide, ➔: water guide.

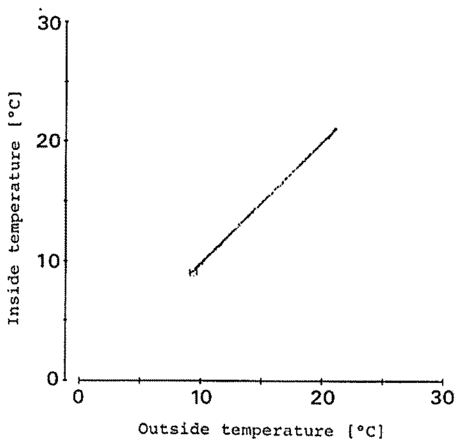

Fig. 2. Air temperature inside and outside the assimilation chamber, on 27 October, 1985.

Ltd.) with a variable transformer after CO_2 content in the air has been stabilized in two air buffers, each of which has a volume of $1m^3$ and a fan. The amount of ventilation is usually kept at 40 m^3 h^{-1} during the daytime and 8 m^3 h^{-1} during the nighttime, as measured by an orifice type flow meter (FEG-S; Nippon Flow Cell Co., Ltd.). The temperature of the air passing through the flow meter is measured for the calculation of CO_2 gas-exchange rates. Air in the chamber is stirred at a flow rate of 480 m^3 h^{-1} by an air-mixing fan.

iv. Carbon dioxide analysis unit

Air at the inlet and outlet of the chamber is alternatively sucked through vinyl tubes into an infra-red gas analyser (MC-D3A; Koito Ind., Ltd.), to measure CO_2 content in the air. A computing element calculates the difference in CO_2 content between incoming and outgoing air. The sampling sequence is regulated at desirable intervals by a stream selector. The tubes are heated by aerial frame heating wires (DP8153 ; Matushita Elect. Works, Ltd.) to avoid the condensation of water vapour in the air inside them.

v. Data acquisition and process control unit

Signals of such factors as the temperature, illuminance, and CO_2 content are recorded on a floppy disk with a storage capacity of 320 kbyte at prescribed intervals through an analog-digital converter (KODIC-20 ; Koito Ind., Ltd.) by means of a microcomputer (PC-8801 ; Nippon Elec. Co., Ltd). The operating time for an 15-channel system using a 3-minute interval call gives a total working time of 15 days. These data are also monitored on analog recorders, as well as on such digital recorders as the CRT-display and printer, both connected with the microcomputer. Furthermore, the microcomputer modulates the cycles of the ventilation and data acquisition.

3. CO_2 gas-exchange measurement

Measurement started in October 1985 on a sample tree within an 11-year-old plantation of *Chamaecyparis obtusa* (Siebold & Zucc.) Endl. growing in an experimental field of the Faculty of Agriculture, Nagoya University. The tree height and diameter at clear length were 3.6 m and 4.6 cm, respectively. The foliage area was tentatively estimated to be 4.6 m^2 on the basis of an allometric relationship between leaf area per tree and its diameter at clear length, obtained for a *C. obtusa* plantation (Hagihara and Hozumi 1986). Radiation was measured above the crown using a photometric sensor (LI-210SB; LI-COR, Ltd.).

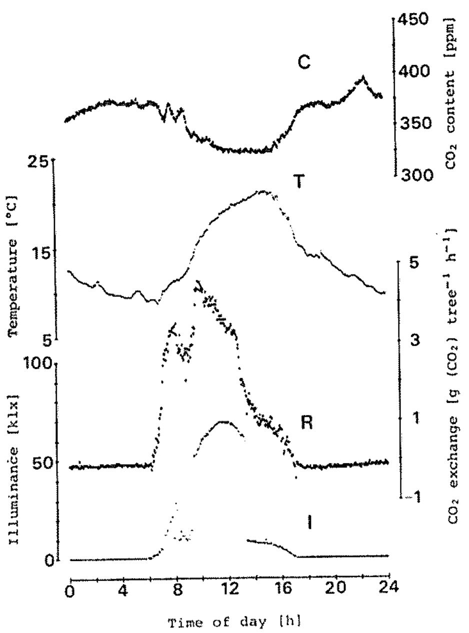

Fig. 3. Diurnal changes in CO_2 gas-exchange rate (R), illuminance above the tree crown (I), air temperature inside the chamber (T), and CO_2 content in the air entering the chamber (C), on 27 October, 1985.

Figure 3 gives an example of the diurnal course of CO_2 gas-exchange plotted together with air temperature inside the chamber, CO_2 content in the air entering the chamber, and illuminance. It can be seen that the CO_2 absorption rate synchronized with the luminous flux density. However, the CO_2 absorption rate was lower in the midday than in the morning at the same intensity of solar radiation, as has been reported for 1-year-old *C. obtusa* seedlings by Negisi (1966).

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