Plant Prod. Sci. 9(2) : 152 — 155 (2006)

【Short Report】

A Multichannel Automated Chamber System for Continuous Measurement of Carbon Exchange Rate of Rice Canopy

Keisuke Katsura[1], Shuhei Maeda[2], Takeshi Horie[2] and Tatsuhiko Shiraiwa[2]

([1]Experimental Farm, Kyoto Univ., Hatchonawate 12–1, Takatsuki, Osaka 569-0096, Japan;
[2]Graduate School of Agriculture, Kyoto Univ., Sakyo-ku, Kyoto, 606-8502, Japan)

Key words : Automated chamber system, Canopy photosynthesis, Carbon exchange rate, Chamber effect, Measurement method, Rice.

Recent studies on high yielding rice suggest that the yield potential is more limited by source production than by sink size (Peng et al., 1999). The source production in the field depends primarily on the canopy carbon exchange rate (CER) which itself is a highly integrated process as a function of plant factors such as photosynthetic and respiratory properties, leaf area index, canopy architecture, and environmental factors. For increased source production in rice, it is important to identify the factors that limit CER under field conditions. This necessitates the measurement of crop canopy CER under field conditions.

Various systems have been developed and utilized for the measurements of crop canopy CER; those included the closed chamber (Takeda, 1961; Saitoh et al., 1998), open-top chamber (Collins et al., 1995) and aerodynamic CO_2 flux measurement systems (Inoue et al., 1958; Toda et al., 2000). Each of these systems has advantages and disadvantages. While the aerodynamic system allows measurement of CER under non-disturbed natural conditions, it requires a sufficiently large fetch, which limits its applicability for genotype-comparative CER measurements. The closed chamber system may give accurate CER data, but its requirement of air conditioner to suppress inside temperature rise not only makes the system costly but also creates a chamber environment largely different from the field, which was referred to as the chamber effect (Kobayashi, 2001). The open-top chamber system has intermediate characteristics between the above two systems, but possible mixture of outside air with the inside air limits the accuracy of CER measurements. Thus, an ideal crop CER measurement system may be such that allows accurate, long-term and simultaneous CER measurements on different genotypes under field-like conditions with modest construction costs.

Employing the periodically closing chamber method that has been frequently utilized for measurements of methane emission rate from soil-plant system (Wassmann et al., 2000; Nishimura et al., 2004), we developed a multichannel automated chamber system for continuous measurement of CER of rice canopy. This system was applied for long-term CER measurements for three rice cultivars. The chamber effects accompanying this system were evaluated by comparing the estimated biomass production from CER measurements with that measured by periodic harvesting of the rice crop grown outside the chamber. This paper describes the system and its characteristics.

Materials and Methods

1. Multichannel automated chamber system

The multichannel automated chamber system devised for rice consisted of four chambers, a computer control system for regulation of chambers, measurement devices, and an infrared CO_2 gas analyzer (IRGA). The top lid of the chamber was open most of the time to allow the inside air to mix with the outside air, and closed only for CER measurement, which usually took 3 min. The change of CO_2 concentration ($[CO_2]$; ppm) in the chamber after the chamber was closed was measured, and CER ($mgCO_2m^{-2}s^{-1}$) was calculated by the following formula,

$$\mathrm{CER} = -44\times10^{3}\times\frac{d[CO_2]}{dt}\times\frac{1.013\times10^{5}}{8.31\times(273+T)}\times\frac{V}{S} \quad (1)$$

where, V and S are the volume (m^3) and floor area (m^2) of the chamber, T the temperature inside the chamber (°C), and t the elapsed time (s).

The chamber was a transparent rectangular box with internal dimension of 0.3 × 0.6 × 1.25 m (L × W × H) made of clear acrylic plate with the thickness of 5 mm (Fig.1). The chamber had an acrylic plate lid hinged at the top of the sidewall. A cylinder piston

Received 13 June 2005. Accepted 23 September 2005. Corresponding author : K. Katsura (kkatsura@kais. kyoto-u.ac.jp, fax +82-72-683-1532).

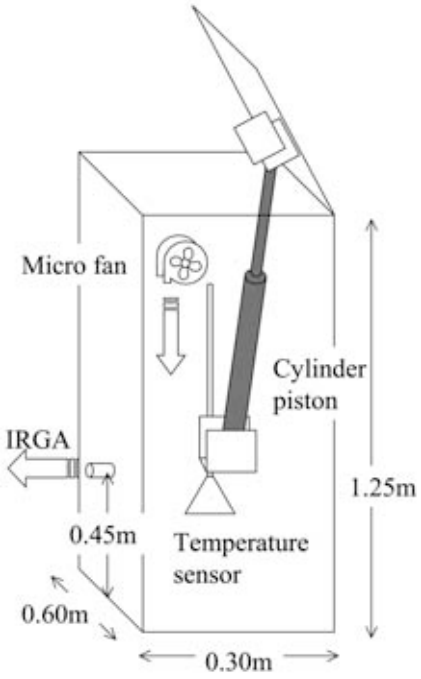

Fig. 1. Schematic drawing of the chamber for measuring carbon exchange rate (CER) of rice canopy. For further explanations, see the text.

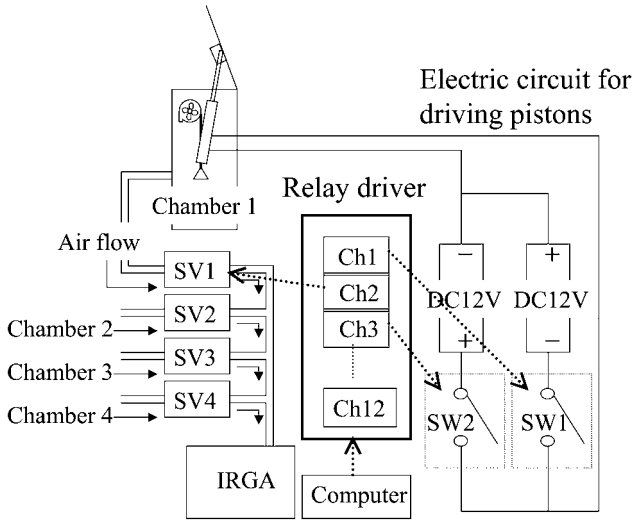

Fig. 2. Schematic representation of the computer control system installed in the multichannel automated chamber system for measuring rice CER. IRGA, SVs, Chs and SWs denote infrared gas analyzer, solenoid valves, computer signal channels and electric switches, respectively. The air from each chamber was switched by solenoid valve and led to IRGA.

(LPF010H3.0, TSUBAKI EMERSON, Japan) attached to the edge of the lid controlled the open-close movement of the lid. A polyurethane rubber gasket was attached to the top of the sidewalls to ensure a gas-tight seal with the lid. A micro fan (MB6U-B, ORIX, Japan) was attached to a sidewall to facilitate the mixture of chamber air. Inside air temperature was measured at 0.50 m above the ground with a radiation shielded waterproof thermometer (TR-52, T and D, Japan). When the chamber lid was closed, the chamber air was led to IRGA (ASSA-1100, HORIBA, Japan) at 67 mL s^{-1} by a pump through a polyethylene tube with an internal diameter of 8 mm.

The system was equipped with four chambers; three were for measurement of rice CER and one for measurement of soil respiration as a blank. Lid movements of the four chambers and airflow from the chambers to IRGA were controlled by a computer control system (Fig. 2). The control devices allocated to each chamber were one solenoid valve for controlling airflow to IRGA, two switches for regulating the open-close movements of the lid and three channels of the relay driver for regulation of computer signal. For the measurement of crop CER in chamber 1, the computer signal through channel 1 turns on switch 1 to close the chamber lid, and the computer signal through channel 2 opens the solenoid valve to lead chamber air to IRGA. After measurement for three min, the computer signal through channel 3 turns on switch 2 to open the chamber lid and the computer signal through channel 2 closes the solenoid valve. This procedure is repeated for the four chambers.

2. Plant materials and measurements

On 26 May in 2004, 23-day-old seedlings of rice cultivars of Takanari (indica × japonica cross-bred), Nipponbare (japonica) and Liangyoupeijiu (Chinese F1 hybrid) were transplanted at a density of two plants per 0.3×0.15 m^2 in the paddy field of Graduate School of Agriculture, Kyoto University, Kyoto, Japan. Amounts of fertilizer applied were 14, 14 and 14 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. N was applied in 4 splits. Each cultivar was grown at three replications for determination of biomass growth, one replication of which was subjected to CER measurement. Plants were grown under flooded conditions until one week before maturity.

The measurement of CER started on 13 July around the panicle initiation stage of Liangyoupeijiu and continued till maturity of each cultivar. Four hills of each cultivar were covered by the chamber for measurement of CER. Bare soil without rice plants was similarly covered with the chamber as a blank. The 3-min measurement of CER was repeated for each chamber at 30-min intervals throughout the day. The CER values for each cultivar were adjusted with the soil respiration rate measured in the blank chamber. At about 10-d intervals, the plants inside the chambers were harvested, and 4 new hills for each cultivar were covered by the chamber for CER measurement.

The biomass accumulation estimated from the CER

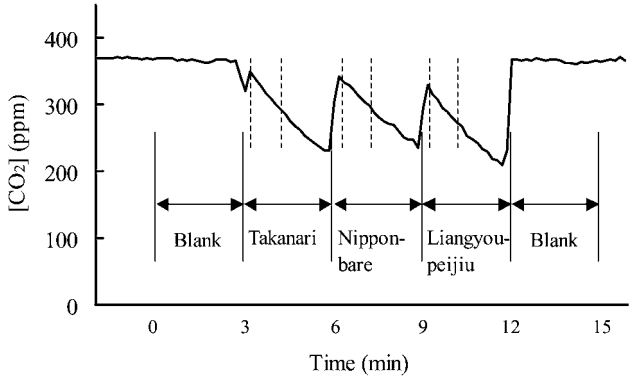

Fig. 3. Changes with time in CO_2 concentration [CO_2] in the chamber air during one cycle of measurements for 4 chambers for blank, Takanari, Nipponbare and Liangyoupeijiu measured on 22 July, a typically clear day. The slope of [CO_2] change between the two dotted lines for each cultivar was used for calculation of CER.

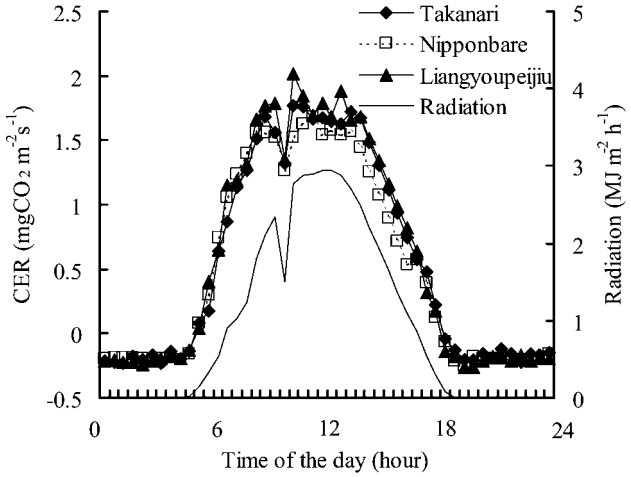

Fig. 4. Diurnal changes in radiant energy and canopy CER of the 3 cultivars of Takanari, Nipponbare and Liangyoupeijiu measured on 22 July, a typically clear day.

measurement was compared with that determined by periodic measurement of the dry weight of crops grown outside the chamber for each cultivar with three replications. The plants were harvested at a 1-week interval, and weighed after oven-drying for 3 days.

Results and Discussion

When the chamber lid was open, the inside temperature was 1 to 2°C lower than that above the canopy due to evaporative cooling. Upon closure of the lid, the inside temperature started to rise, but the maximum change during the 3-min closure was 1.5°C (data not shown). Since the chamber lid was closed for only 3 min and left open for the subsequent 27 min, this temperature rise was considered to have only minor effects on the plants.

Fig. 3 exemplifies changes with time of CO_2 concentration [CO_2] during one cycle of measurement for the blank, Takanari, Nipponbare, Liangyoupeijiu and again blank chambers at midday on a typically clear day (22 July). After closing of the lid of each crop chamber, [CO_2] declined almost linearly with time; it declined more rapidly in the chambers containing Takanari and Liangyoupeijiu than in the chamber containing Nipponbare. The initial slope of [CO_2] decline between the two dotted lines for each cultivar in Fig. 3 was used for calculation of CER by Eqn. (1). It appeared that the 3-min closure for CER measurement was too long and a 2-min closure would have been sufficient. No appreciable changes in [CO_2] were observed in the blank chamber, presumably due to suppression of soil CO_2 flux by water layer above the soil.

Diurnal changes in CER of the three cultivars measured on 22 July, a typically clear day are shown in Fig. 4. A clear genotypic difference in the CER was observed among these cultivars: Takanari and

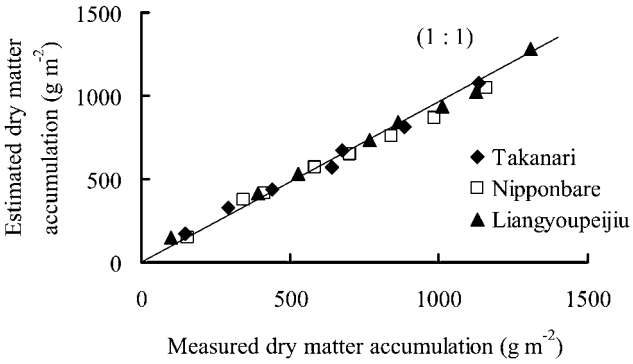

Fig. 5. Relationships between aboveground dry matter accumulation measured by periodic crop harvesting and that estimated by summing CER measured at 30-min intervals for the periods from about panicle initiation to maturity for cultivars Takanari, Nipponbare and Liangyoupeijiu. For further explanations, see the text.

Liangyoupeijiu showed higher CER than Nipponbare. The increase of aboveground biomass was calculated for each cultivar by summing the CER measured for each 30 min for the entire period of measurement from about panicle initiation to maturity, thereby CER was converted to biomass by multiplying with 30/44 for CH_2O/CO_2. The biomass growth estimated from CER for each cultivar was then compared with that measured in the field (Fig. 5). The estimated biomass growth for each cultivar agreed well with that directly measured with 3 replications.

Any chamber system including the present one may create different environments (temperature, radiation, humidity, wind and so on) inside the chamber, which may have certain effects on the plants (chamber effect). However, the good agreement between the biomass production estimated from CER

measurements and that measured for the rice crop grown outside the chamber suggests that chamber effects in the present system were negligibly small, as long as the CER measurement on the same plants was within about a 10-d period. In conclusion, the multichannel automated chamber system presented here for measuring CER is suitable for long-term, continuous and automatic measurements of rice CER and provides reliable CER data with only minor chamber effects.

References

Collins, L.B. et al. 1995. In S. Peng ed., Climate Change and Rice. Springer-Verlag, Berlin, Germany. 232-243.

Inoue, E. et al. 1958. J. Agric. Meteorol. 14: 45-53*.

Kobayashi, K. 2001. Jpn. J. Crop Sci. 70 : 1-16**.

Nishimura, S. et al. 2004. Global Biogeochem. Cycles 18 : GB2017.

Peng, S. et al. 1999. Crop Sci. 39 : 1552-1559.

Saitoh, K. et al. 1998. Plant Prod. Sci. 1 : 106-112.

Takeda, T. 1961. Jpn. J. Bot. 17: 403-437.

Toda, M. et al. 2000. J. Agric. Meteorol. 56 : 195-207.

Wassmann, R. et al. 2000. Nutr. Cycling Agroecosyst. 58 : 1-12.

* In Japanese with English summary.

** In Japanese.