# Chamber Method for Estimating the Primary Productivity or Rice Plant Population

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Studies on photosynthesis of crop population by using the chamber method with $CO_2$ gas analysis have been approached from two sides: one is the direct measurement of photosynthesis of a crop population, and the other is the indirect approach using the leaf chamber, by which photosynthetic activities of individual leaves constituting the crop population are measured and a model of the total photosynthesis of that crop population is constructed to simulate it.

For the direct measurement of population photosynthesis, an assimilation chamber made of plastic plate or vinyl sheet is covered over a plot containing a certain number of plants of the crop population under field conditions. Sending air into the chamber with a blower and determining the inlet and outlet $CO_2$ concentrations of the air stream, the rates of photosynthesis and respiration of the plants in the chamber can be calculated.

As for the volume of air to be supplied to the chamber, there have been no specified rules to be adopted. When the rate of air supply is inadequate, various undesirable troubles will happen, e.g. sharp rise of temperature and $CO_2$ deficiency inside the charmber, making the environmental condition in the chamber considerably different from the outdoor condition.

In such a case, it is presumed that the value of dry matter productivity calculated on the basis of data obtained by the chamber method will be lower than that under natural conditions.

It is a serious problem if it occurs that the integrated value of photosynthesis and respiration measured by the chamber method does not coincide with the actual Crop Growth Rate (CGR) under natural conditions. As a principle, both values must coincide with each other. At least, under the assumption that both values coincide with each other, the results obtained by the chamber method can be used for estimating CGR and are applicable in studying various related aspects.

In the present paper, discussion will be made on the following four problems:

1) Problems which apt to occur with the chamber method, when sufficient considerations are not given on the environment in the chamber.

2) Whether the dry matter productivity theoretically estimated on the basis of chamber method coincides with the actual one or not ? If they do not agree, what would be the reason ?

3) If they coincide with each other, what are the conditions required for it ? It should be an important work to establish a measuring method, which can give a good coincidence.

4) These points are important not only for improving the chamber method, but also as the problem of experimental ecology.

## Assimilation chamber used for field photosynthesis measurement

Changes in photosynthesis during the daytime and respiration during the night were determined by measuring $CO_2$ uptake and dis-

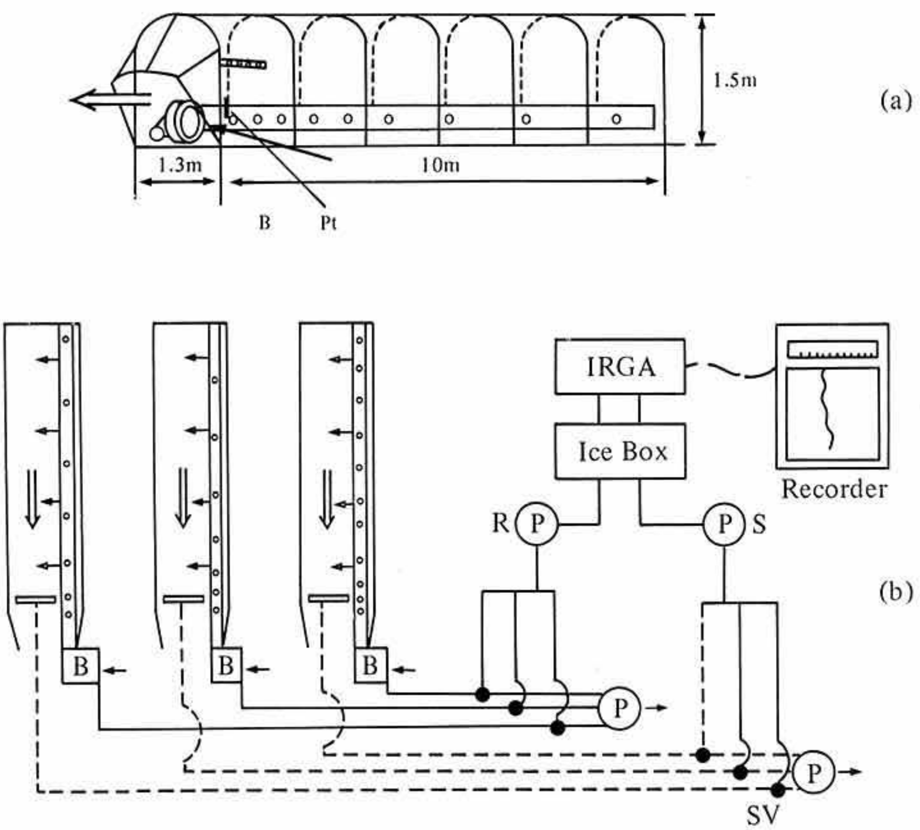


Fig. 1. Schematic diagram of the assimilation chamber for field photosynthesis measurement (a), and flow diagram of $CO_2$ concentration analysis (b). B; blower to send outdoor air to the chamber, Pt; Pitot tube for monitoring the air flow rate, P; air pump, SV; solenoid valve

charge in assimilation chambers. Schematic diagram of the chamber and flow diagram of $CO_2$ concentration analysis are shown in Fig. 1. Each assimilation chamber consisted of iron frame and vinyl film, and the size was 1.3 m in width, 10 m in length and 1.5 m in height. One end was opened and the other closed. Each chamber covered 5 rows of rice plants totaling 240 hills. Air was supplied to the chamber by a blower through a long duct from the open end. No equipment to control temperature inside the chamber was installed, because the difference between inside and outside temperature was not so large.

The rates of air supply to the chambers were 19.1 $m^3$/min, 75.6 $m^3$/min, and 122 $m^3$/min, or in the mean wind speed per cross section of the chamber, 0.15, 0.6, and 1.0 m/sec, respectively. At these rates of air supply, the air in the chamber was replaced 39, 156, and 246 times/hr.

## Comparison of CGR observed by biomass method and that by chamber method

By comparing the environmental factors inside the chamber with those under natural conditions, it was found that the difference increased with the increase of solar radiation.[1] The difference decreased as air supply increased, and when the ventilation rate was

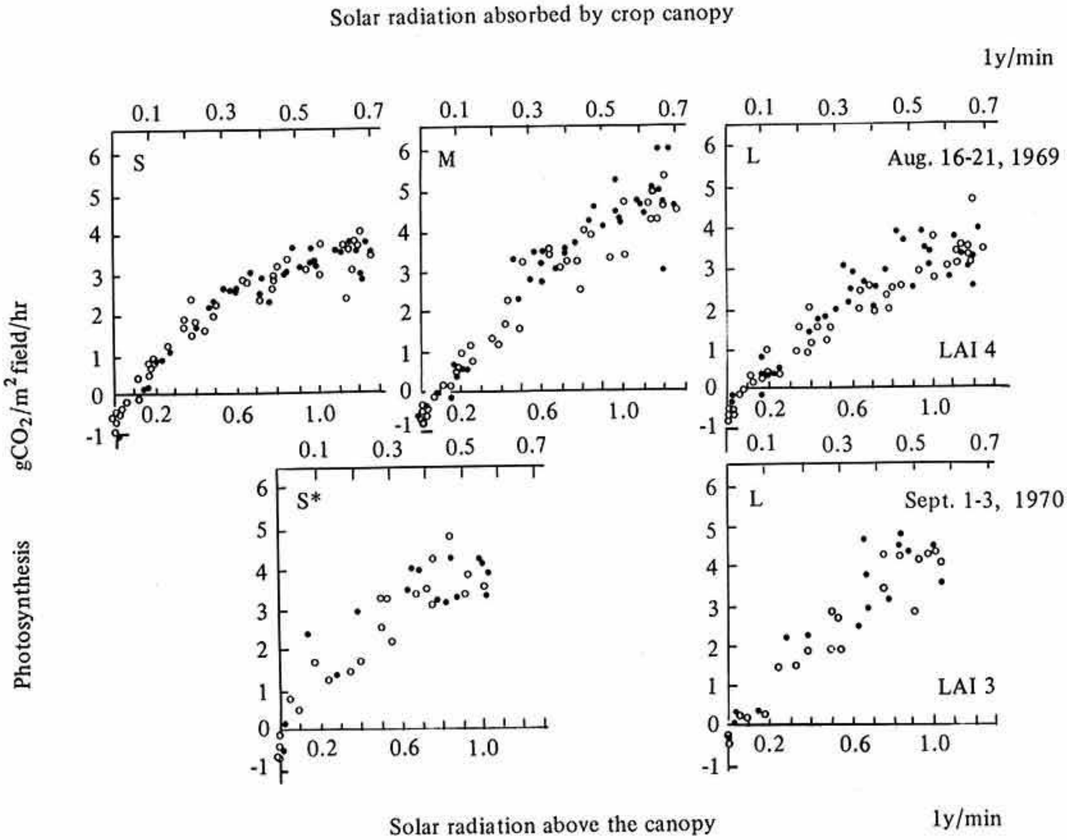


Fig. 2. Effect of air supply to the chamber on light- photosynthesis curves in rice plant population. The black circles show the results in the morning and the hollow circles in the afternoon. Ventilation rates of the chamber S. M. L. and S* are 39, 156, 246, and 74 times/hr, respectively

medium or relatively high, environmental factors inside the chamber were kept almost equal to the outside ones.[4]

At a low rate of air supply to the chamber, the light-photosynthesis curve of rice plant population showed a light-saturated form. However, with an increase of air supply, the photosynthetic rate under strong light intensity was increased and as a result the shape of the light-photosynthesis curve became more linear (Fig. 2).

Comparisons of CGR observed by the biomass method and that by the chamber method under different rates of air supply are shown in Table 1. At the stage when LAI was rather small (LAI 3, 1970), the effect of ventilation rate was small and CGR obtained by both methods coincided well. But, when LAI was larger e.g., 4 or 5, and air volume supplied to the chamber was small, CGR inside the chamber was apparently less than that outside the chamber. The inside CGR increased with the increase of air supply, and became close to CGR under natural conditions. In any case, the inside CGR determined by the biomass method should naturally coincide well with CGR determined by the chamber method.

This result indicates that at a certain rate of air supply the inside CGR coincides well

Table 1. Comparison of CGR obtained by biomass method and that by chamber method

| | | Biomass method | | Chamber method | Ratio | |
|---|---|---|---|---|---|---|
| | | ΔW | ΔW′ | ΔW″ | ΔW′/ΔW | ΔW″/ΔW |
| | | | g/m²/week | | % | % |
| Aug. 16-22 | C | 139 | | | | |
| 1969 | S | | 101 | 95 | 73 | 68 |
| | M | | 173 | 150 | 124 | 108 |
| LAI 4 | L | | 139 | 100 | 100 | 72 |
| Aug. 31-Sept. 6 | C | 310 | | | | |
| 1969 | S | | 181 | 144 | 58 | 45 |
| | M | | 237 | 267 | 76 | 86 |
| LAI 5 | L | | 277 | 206 | 89 | 66 |
| Aug. 22-Sept. 4 | C | 170 | | | | |
| 1970 | S* | | 171 | 151 | 101 | 89 |
| | M | | 153 | — | 90 | — |
| LAI 3 | L | | 174 | 148 | 102 | 87 |

Note : W : CGR of the population outside the chamber.
W′ : CGR of the population inside the chamber.
W″ : CGR theoretically calculated from $CO_2$ measurement.
C : Outdoor condition.

with outside CGR. So far as the present experiment is concerned, it is about 75 m³/min. However, it may not be expected that this value is applicable to all cases, because the optimum air volume supplied to the chamber might be a function of LAI, potential photosynthetic activity of individual leaves constituting the canopy, and the crop micro-environment.

## Analysis of the discrepancy

To clarify the factors responsible for causing such a discrepancy between the inside CGR obtained by the chamber method and the outside CGR, it is necessary to examine the constituents of the field photosynthesis. Therefore, light-photosynthesis curves of rice leaves,[3] productive structure, and profiles of light intensity and $P_{max}$ (light saturated values of leaf photosynthesis) in the canopy were measured from the tillering stage to the ripening stage.[3,5]

Using the parameters obtained from the measurements, the theoretical CGR was developed according to Uchijima's semiempirical model,[6] and was compared with CGR obtained by biomass method. The result showed that the theoretical values almost coincided with the values obtained by the biomass method.[5] It shows that the mathematical model can be used to analyze the discrepancy. Sensitivity analysis of the model and comparison between theoretical light-curve and observed values of field photosynthesis are shown in Fig. 3. In Fig. 3, observed values of field photosynthesis were obtained from chamber M and the CGR estimated by that chamber showed a fairly good coincidence with the natural CGR obtained outside the chamber.

Then, by adopting the most suitable curve as a standard curve, unmeasured parameter ($P_{max}$ H) was determined.

In the model, the following assumptions were used.

$$P_{max}(F) = \frac{C}{r_a(F)+r_{S,M}(F)} f(\theta) \qquad (1)$$

where, $P_{max}(F)$; light saturated value of leaf photosynthesis at the downward cummulative LAI from top of the canopy, F., C; $CO_2$ concentration in the air, $r_a$; boundary resistance of a leaf to $CO_2$ transfer, $r_{S,M}$;

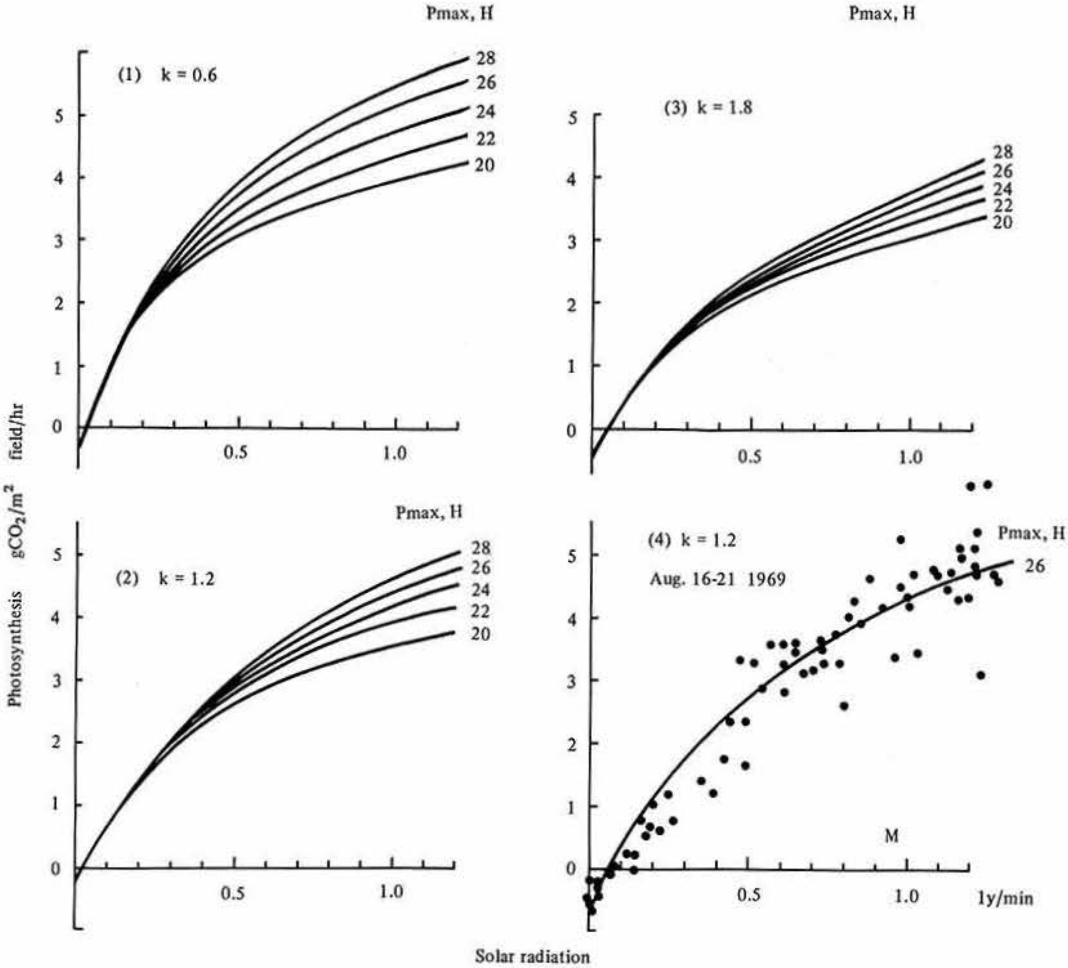


Fig. 3. Theoretical light-curves estimated by Uchijima's model. (1), (2), (3) : Effect of $P_{max,H}$ and k on the population photosynthesis. (4) : Examination of the fitness of the theoretical light-curve to the data obtained from field photosynthesis measurement with chamber M (Aug. 16-21, 1969).

$P_{max,H}$ : light satutated value of leaf photosynthesis at top of the canopy. k : light attenuation coefficient in the 'reciprocal model. In calculation. vertical gradient of Pmax in the canopy is assumed 3.59 mg $CO_2/dm^2/hr$ obtained in Aug. 27 and Sept. 5, 1972.

LAI is 4.0.

stomatal and mesophyll resistance, $f(\theta)$; function of temperature effecting leaf photosynthesis.

$$r_a(F) = \text{const}\,(d/u(F))^{0.5} \qquad (2)$$

where, d; leaf width, u(F); wind speed at F in the canopy, and const. is 1.105 (Gaastra, 1959.,[1] Monteith, 1964[2]).

When the amount of air supply to the chamber is increased, wind speed in the chamber is also increased. Therefore, the effect of wind speed, which changes $r_a$, on population photosynthesis was examined, but its effect was not so much, because, $r_a$ is much smaller than $r_{s,M}$.

Next, the effect of temperature and $CO_2$ deficiency on population photosynthesis was evaluated. From the results of leaf photosynthesis measurement,[4] $f(\theta)$ was expressed as follows;

$$f(\theta) = -0.754 + 0.131\,\theta - 0.00245\,\theta^2 \qquad (3)$$

Air temperature inside the chamber was changed linearly with solar radiation (Fig. 4), and maximum depression in $CO_2$ concentration was 15 ppm (in the chamber S) or 5 ppm (in the chamber M). Accordingly these results were used in the mathematical analysis.

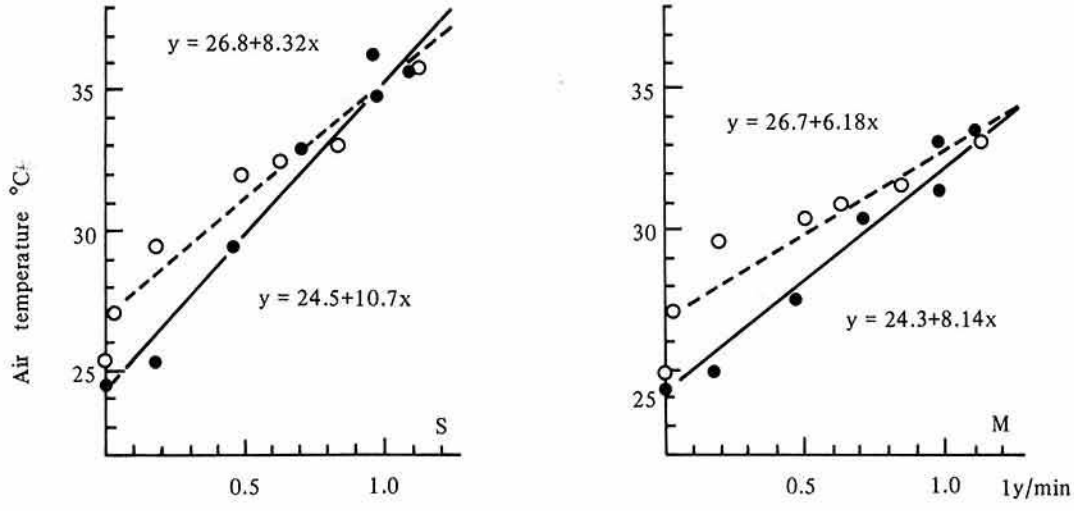


Fig. 4. Relation between solar radiation and air temperature inside the chamber (Aug. 20, 1969). Black circles are the results obtained in the morning and hollow circles in the afternoon.

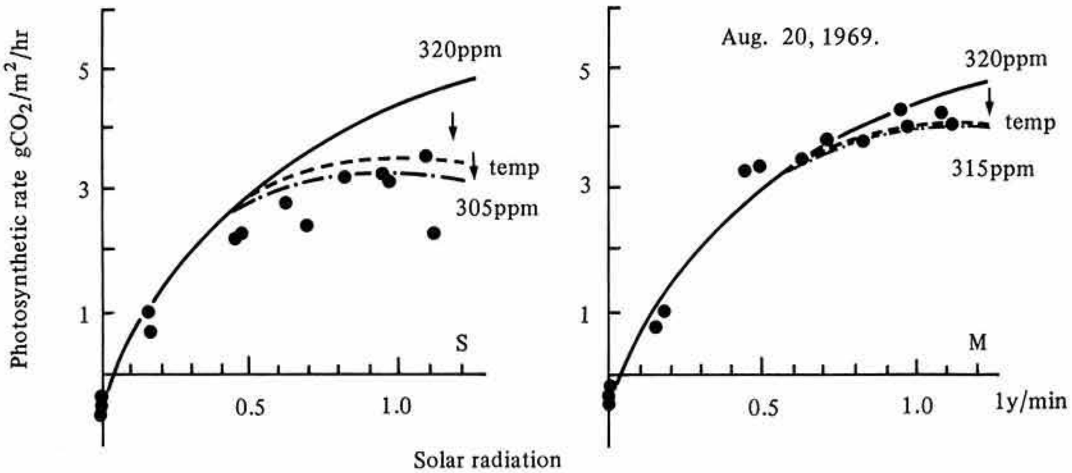


Fig. 5. Theoretical light-curves developed by considering air temperature and $CO_2$ concentration in the chamber. Black circles are the results obtained by photosynthetic measurement with chambers.

———— : standard curve at the assumptios of leaf temperature, 30℃, and 320 ppm $CO_2$.

– – – – – : light-curve at the daily change of air temperature inside the chamber.

–·–·–· : light-curve at air temperature and $CO_2$ concentration inside the chamber.

Results are given in Fig. 5, which shows that at a low rate of air supply, the main cause for the decreased photosynthesis was high temperature inside the chamber, and the depression of $CO_2$ concentration also affected it a little.

A further experiment proved that the main cause for the reduced dry matter production of rice plant population under a high wind speed was the decrease of light penetration into the canopy.

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