# 日本作物學會紀事

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(*Nihon Sakumotsu Gakkai*)

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# Studies on the Photosynthesis of Forage Crops

## 1. Diurnal changes in the photosynthesis of several grasses and barley seedlings under constant temperature and light intensity. *

Yoshio MURATA and Junichiro IYAMA

(*National Institute of Agric. Sciences*)

## Introduction

The problem whether there are diurnal changes in the photosynthesis even under completely constant conditions, that is, whether there exists an internal rhythm in photosynthesis, is one of those fundamental problems which we always encounter not only at studying the diurnal course of photosynthesis itself but also at making inquiries of any kind into photosynthetic ability of crop plants.

Although the problem has been discussed since comparatively early days, it can not yet be said that a clear-cut conclusion has been reached.

According to the monograph of RABINOWITCH[1], FILZER (1938), for example, observed that leaves, picked from a tree at different times of the day and placed under constant laboratory conditions, showed the same periodic changes in photosynthetic production as did leaves left attached to the tree standing outside. MASKELL (1928) reported that, when detached leaves were exposed to continuous illumination, photosynthesis of cherry laurel fell to a very low level during the night hours, whereas that of *Hydrangea* leaves showed only a slight decline.

The present senior author[2] observed that rice leaves, sampled in the field successive times of the day and investigated of their photosynthetic activity under constant light and temperature, using the outdoor air, showed somewhat low activity around noon. Recently BELKOV and MOTORINA[3] have found rhythms in the photosynthesis of Saks beans grown under continuous illumination.

On the other hand, in some plants, e.g., wheat[4], apple[5], ginseng[6], etc., any rhythm in their photosynthesis has so far not been detected under constant conditions.

As it was considered from these results that plant species might play a part in the problem, we have decided to start our study on the photosynthesis of forage crops by picking up this problem in the first place.

## Materials and Methods

The following six crops were used: Italian ryegrass, orchard grass, ladino clover, common vetch, barley and rye. Seedlings of these crops were soil-cultured for 30 to 50 days in small pots, 600 ml polyethylene beakers, containing twenty seedlings each.

Experiments were conducted from Nov., 1961 to May, 1962 one after another. Measurement of photosynthesis and respiration was made by the apparatus designed and constructed by the authors for seedling plants (Fig. 1). A Beckman Infrared Gas Analyzer Model 15 A is installed in the apparatus for analyzing the carbon dioxide concentration at the entrance and exit of the twelve assimilation chambers in succession. The chambers are enclosed in a large, air-conditioned box to keep the inside temperature constant, in the range from zero to 50°C, with possible fluctuations less than 1.5°C, under an illumination up to 40 kilolux by a 300-watt incandescent reflector type flood lamp for each chamber.

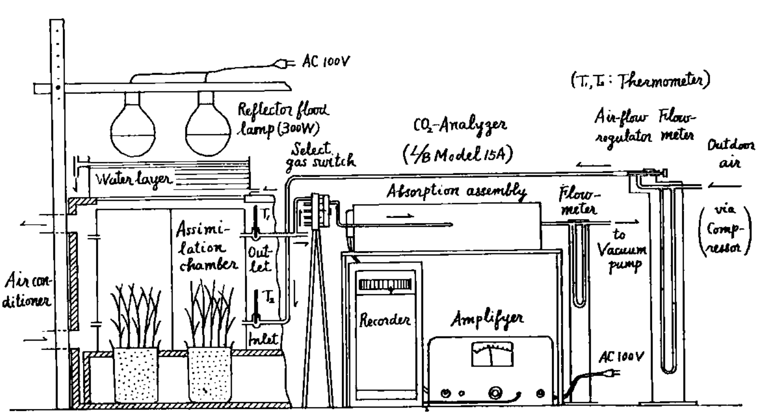


Fig. 1 Apparatus for measuring photosynthesis of seedling plants

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Changes in the apparent photosynthesis of the six different crops were followed by the above apparatus at a constant temperature, 15°C, and a light-intensity, 40 kilolux, for a whole day, using the outdoor air as $CO_2$ source. Respiration rate was also followed in darkness at the same time and temperature, with similar samples. Both apparent photosynthesis and respiration rates were expressed in mg $CO_2$ per chamber (20 seedlings) per hour.

## Results

**1. Diurnal changes in the rate of apparent photosynthesis and respiration in the daytime.**

In the case of Italian ryegrass, it was observed, Fig. 2A, that the rate of apparent photosynthesis showed some fluctuations in the course of a day even under constant temperature and light conditions: it was higher in the morning, fell a little thereafter, and rose again late in the afternoon. The changes, however, coincided very closely with those of $CO_2$ conc. in the air. This is more clearly recognized in Fig. 2B, where a linear relationship is seen between the efficient $CO_2$ conc. in the chamber, that is, the arithmetic mean of the inlet and outlet concs. and the rate of apparent photosynthesis.

Respiration rate, on the other hand, showed a slight, linear decrease with time, independent of the $CO_2$ conc.

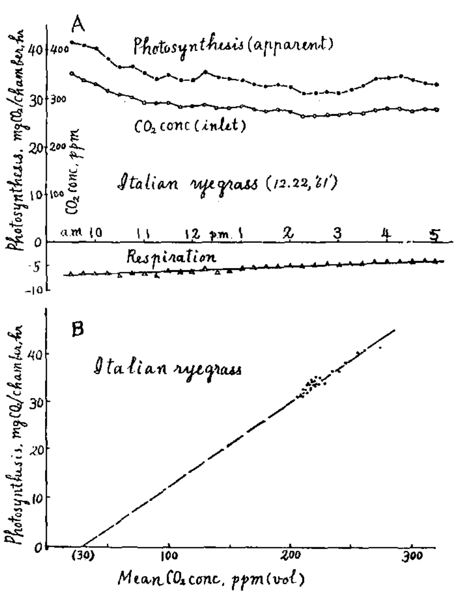


Fig. 2 Diurnal changes in apparent photosynthesis and respiration (A) and their relationship to $CO_2$ conc. in assimilation chamber (B) in Italian ryegrass

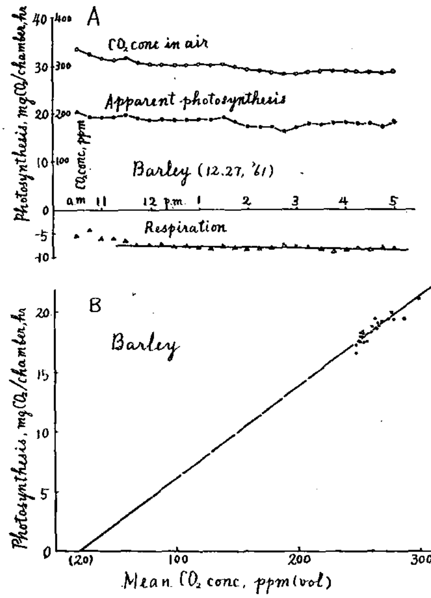


Fig. 3 The case of barley. Items are the same as Fig. 2.

The same was observed in the apparent photosynthesis of barley (Fig. 3), orchard grass (Fig. 4) and ladino clover (Fig. 5), though slight differences in trend among crops were found in the case of respiration rate.

From these results it may be concluded as follows :

Though it seems at first sight that diurnal changes exist in the apparent photosynthesis of all these crops, even under the constant conditions, the true cause of the changes lies in the fluctuations of $CO_2$ conc. in the air.

As for the changes in respiration rate in the dark, slight differences were observed among species from completely constant one to slowly decreasing or increasing one.

**2. Diurnal changes in the rate of apparent photosynthesis and respiration in a whole day.**

A 24-hour observation was made with seedlings of rye and common vetch (Fig. 6A) to determine whether the above-stated results could also be applied when the time was extended to a whole day including the night hours.

In the case of rye seedlings, the apparent photosynthesis showed such diurnal changes as were completely explained by the fluctuations in the $CO_2$ conc. alone throughout the whole day, just as the daytime cases described above. In the case of common vetch, however, a certain depressing factor for photosynthesis, other than $CO_2$ conc., appeared in the night hours (Fig. 6 B), so that the $CO_2$-photosynthesis relationship was expressed by two different lines, in contrast to a single line in the case of rye seedlings. Respiration rate, on the other hand, showed a slowly, ever-decreasing tendency in both the seedlings.

## Discussion

The fact that there were linear relationships found, at least in the daytime, between the effective $CO_2$ conc. in the chamber and apparent photosynthesis in all the six crops, means that there exists no rhythm in photosynthesis at all, that is, if not only the temperature and light-intensity but also $CO_2$ conc. in the air are kept constant, there will be no substantial changes seen in their apparent photosynthesis.

However, in the case of common vetch in the 24-hour experiment, there was really a certain depressing factor for photosynthesis, other than $CO_2$ conc., though the cause for it has not been shown in this report. Closure of stomata might be responsible for it, as MASKELL[1], STÅLFELT[7] and others said, or it might be a sort of phenomenon so-called fatigue[1]. Judging from the fact that depression in photosynthesis continued still the next morning, it seems that the latter case is more probable than the former, though the problem still remains to be proved.

## Summary

Diurnal changes in photosynthesis and respiration of seedling crops under constant temperature (15° C) and illumination (40 kilolux), were observed by an apparatus in which a Beckman Infrared Gas Analyzer was installed, using the outdoor air as $CO_2$ source. The crops used were ; Italian ryegrass, orchard grass, rye, barley, ladino clover and common vetch.

In all the six crops examined, diurnal fluctuations in apparent photosynthesis were observed even under these constant conditions. However, it was revealed out that the fluctuations should entirely be attributed to the changes in $CO_2$ conc. in the air. It was, therefore, concluded that, when not only temperature and light-intensity but also $CO_2$ conc. were kept constant, there would be no substantial fluctuations in photosynthesis, at least in the daytime. However, when the experiment period was extended further to 24 hours, it was observed in a crop, common vetch, that a certain factor, other than $CO_2$ conc., came into play in depressing the photosynthesis in the night hours.

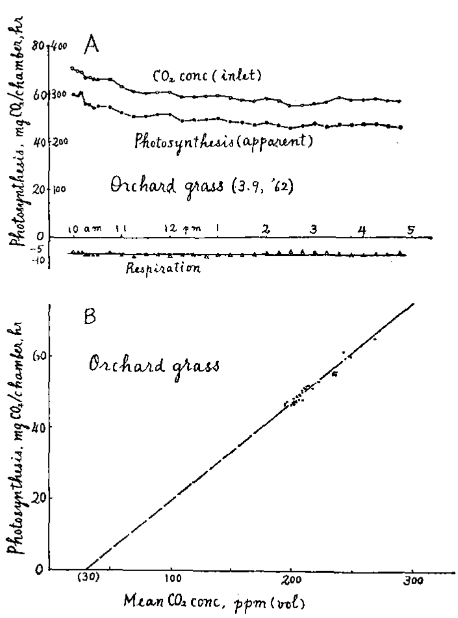


Fig. 4 The case of orchard grass.
Items are the same as Fig. 2.

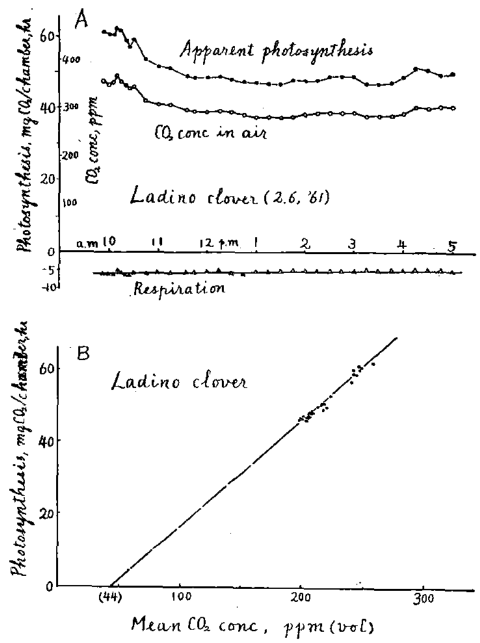


Fig. 5 The case of ladino clover.
Items are the same as Fig. 2.

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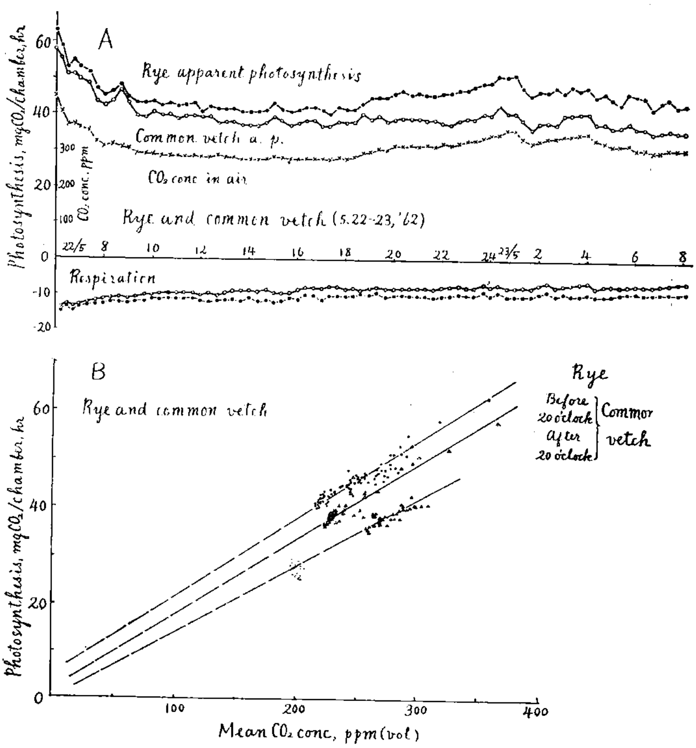


Fig. 6 Changes in apparent photosynthesis and respiration during a 24-hour period (A) and their relationships to $CO_2$ conc. in the assimilation chambers (B) in rye and common vetch.

〔和 文 摘 要〕

## 飼料作物および牧草の光合成に関する研究

### 報1第 数種の牧草および麦類の定温・定照度下における光合成の日変化

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環境条件を完全に一定に保つた場合にもなお光合成に日変化が見られるかどうかを明らかにするために，数種の牧草と麦類（オオムギ，ライムギ，イタリアンライグラス，オーチャードグラス，ラジノクローバーおよびコモンベッチ）の幼植物を用いて，光の強さおよび温度を一定に保つて光合成の日変化を調べた．

小型ポットに土耕した 30～50 日の幼植物（20 個体）を 4 万ルックスの電燈光の 下で 15°C に保つた 同化室に入れ，戸外空気を通じて BECKMAN の赤外線ガス分析器により光合成の測定を行なつた．結果は次の通りである．

1）このような条件の下でも光合成はある程度の日変化を示すことが，調べたすべての作物で認められた．しかしその変化は空気中の $CO_2$ 濃度変化と全く平行した．
2）この関係はライムギの場合には 24 時間以上，昼夜の別なく成立つが，コモンベッチの場合には夜間は $CO_2$ 濃度以外の同化抑制要因が同時に働くことが示された．
3）以上のことから，養水分が十分に与えられ，光・温度および $CO_2$ 濃度一定の環境下では，これらの作物の光合成能力は，夜間には多少の低下を示すものもあるが，一般にはほとんど変化を示さないものと結論された．

# Studies on the Photosynthesis of Forage Crops

## II. Influence of air-temperature upon the photosynthesis of some forage and grain crops*

Yoshio MURATA and Junichiro IYAMA
(*National Institute of Agric. Sciences*)

## Introduction

It does not need to say anew that air-temperature gives profound influences upon the growth as well as the distribution of plants. Directly associated with this are the problem of suitability of crops for a certain district or a season. From this point, it may be quite significant to make clear what influences the air-temperature will give upon photosynthesis and respiration, both of which have a fundamental connection with dry matter production and growth of plants.

A number of studies so far have been published on this subject with various plants. Yet there are comparatively few works which have dealt with it in relation to the productivity or distribution of crop plants, and even fewer are those which have compared the temperature-responses of different crops or species on the same conditions. Among the fewer works are those made by DECKER[1] who compared the temperature-responses in apparent photosynthesis and respiration of red and loblolly pines, by NEGISHI and SATOH[2] who compared the temperature curves of photosynthesis in three tree species, and by MILLER[3] who also compared the temperature curves of photosynthesis of creeping bent grass and Bermuda grass.

In this paper, short-term influences of air-temperature upon the photosynthesis and respiration of twelve different crops are reported.

## Materials and methods

The following grasses and grain crops, twelve in all, were used: Northern type

- Italian ryegrass (Var. Nakei No. 1)
- Perennial ryegrass*
- Orchard grass (Var. Nakei No. 1)
- Ladino clover*
- Chinese milk vetch (Var. Gifu-daibansei)
- Wheat (Var. Norin No. 61)
- Barley (Var. Sekitori-Sai No. 1)
- Naked barley (Var. Akashinriki)
- Rye (Var. Petkuser)
- Common vetch* (Europian strain)

Southern type

- Bermuda grass*
- Bahiagrass

Note:* Purchased from the Yukijirushi-shubyo Co.

Seedlings of these crops were soil-cultured in small pots, 20 plants per pot, for 30 to 50 days as in the previous report, and used for tests. Experiments were carried out from Oct., 1961 to June, 1962 one after another.

Measurement of photosynthesis and respiration was done by the same apparatus reported in the previous paper. The air-temperature of the assimilation chamber was slowly changed in the range zero to 45°C. and the resultant changes in the rate of apparent photosynthesis and respiration were followed. The whole temperature range was divided into two, zero to 20°C. and 15 to 45°C., and temperature-changing was performed in about four hours, using separate samples. All the procedures were repeated twice with new samples. Light-intensity was kept constant at 40 kilolux and the outdoor air was supplied to the chamber during measurement of photosynthesis.

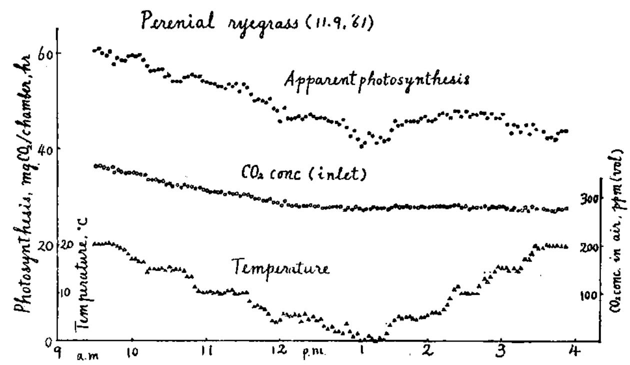


Fig. 1 Examination of measurement-procedures. I. Changes in apparent photosynthesis when the air-temperature was slowly varied.

## Results

### 1. Examination of experimental procedures

There were two problems to be examined beforehand. The first was to determine in what order and at what speed the temperature should be changed, as it is a condition of first importance in this sort of experiment. The second was how to

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avoid or correct the influence of fluctuation in $CO_2$ conc., which is inevitable with the outdoor air and to which photosynthesis is very sensitive.

In the first experiment, the air-temperature in the assimilation chamber was slowly lowered from 20 to 0 °C., then it was raised slowly again to 20°C. and the resultant changes in apparent photosynthesis were observed (Fig. 1). If, in this case, temperature-photosynthesis (apparent) relationship was plotted directly from these data (Fig. 2A), two different curves were obtained, the upper one corresponding to the descending series and the lower one, to the ascending series. At first, it was considered that the discrepancy might represent the phenomenon of fatigue[4]. However, it was rather improbable, considering the comparatively low level of temperature n this case.

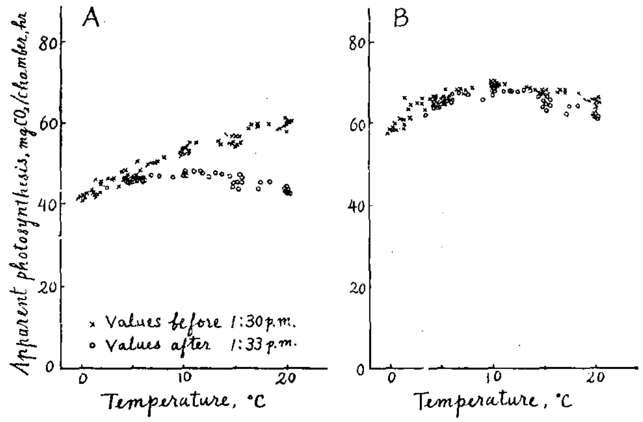


Fig. 2 Examination of measurement-procedures. II. A: Temperature-photosynthesis (app.) relationship based on non-corrected data shown in Fig. 1. B: The same relationship after $CO_2$-correction made.

According, on the other hand, to the authors' previous work[5] and others[6)7)8)9], photosynthesis of higher plants at constant temperature and light-intensity has almost a linear relationship with $CO_2$ conc., in the range from zero to several times normal atmospheric conc. Assuming, therefore, that apparent photosynthesis was proportional to the efficient $CO_2$ conc. in the assimilation chamber, $CO_2$ corrections were made for the above data to get photosynthesis values at 300 ppm $CO_2$. Then, as shown in Fig. 2B, the discrepancy has completely disappeared, giving a single temperature-photosynthesis (apparent) curve.

Further examinations were made on the time of experiment and the order of changing temperature. Fig. 3 shows the temperature-photosynthesis (apparent) curves of perennial ryegrass, derived from various measurements with the $CO_2$ correction made. In spite of the difference in absolute level of each curve, the position of the optimum temperature is almost identical, about 10°C., in all the six curves.

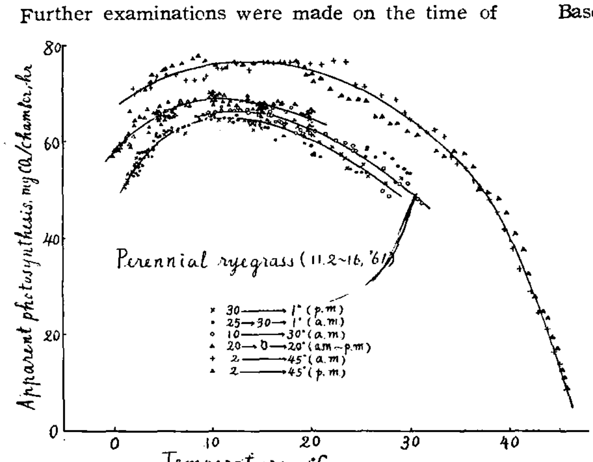


Fig. 3 Examination of measurement-procedures. III. Temperature-photosynthesis (app.) relationships at various times and orders of temperature-change.

From the above examinations, it was concluded that, as long as the $CO_2$ corrections are given to observed values, we can get a correct temperature-photosynthesis relationship, whenever and in what order the temperature-change and the measurement may be done.

Based upon this conclusion, all the experiments were conducted hereafter by the procedures already described, and the temperature-photosynthesis curves were drawn after the $CO_2$ correction made.

**2. Relationships between temperature and apparent photosynthesis and respiration in individual crops**

In barley seedlings (Fig. 4A), apparent photosynthesis showed its maximum at much lower temperature, around 10 °C., than expected, decreasing slowly below or above it and rapidly over 40°C. Respiration rate, on the other hand, showed an exponential increase in the whole temperature range.

In wheat (Fig. 4B), naked barley (Fig. 5A), rye (Fig. 5B), Italian ryegrass (Fig. 6A), perennial ryegrass (Fig. 6B), and Chinese milk vetch (Fig. 7), too, the relationships were almost the same