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Respiration of Soybean Plants in Relation to Their Physiological Conditions

II. Effects of preceding light conditions on the time course change of respiration in the following dark period*

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Abstract: The time course of respiration in the continuous dark was examined with soybean plants having experienced various preceding light conditions, aiming to elucidate the determination mechanism of changes with time in respiration rate.

The initial value of respiration rate per unit dry weight (RPW) observed immediately after the onset of dark period was dependent on the light intensity in the preceding light period, and it was not affected by the length of light period. However, the bottom level of RPW observed after the initial decrease was affected by the length, with the lower levels in the plants exposed to the shorter light period. Furthermore, the magnitude of midnight rise of respiration, the temporal rise in the dark period, was affected by both light intensity and length of light period. It showed the linear relationship against cumulative light intensity which was obtained from light intensity multiplied by length of light period. RPW in nitrogen-depleted plants did not respond to length of light period.

In this experiment, it was found that the time course of respiration consisted of two different phases. One was in the initial part of the dark period and dependent on light intensity. The other was in the following part and dependent on cumulative light intensity in the preceding light period. From this observation, it was considered that respiration in the dark period was regulated by two different physiological processes.
Key words: Diurnal change of respiration, Length of light period, Light intensity, Nitrogen depletion, Respiration, Soybean.

ダイズ植物体の生理的条件と呼吸速度との関係　II 明期の光条件がひき続く暗期における呼吸の経時変化に及ぼす影響：山岸順子・石井龍一・玖村敦彦（東京大学農学部）

要　旨：明期において種々の光条件を経験したダイズ個体の，連続暗黒下における呼吸速度から，呼吸の経時変化が決定されるメカニズムを検討した．

暗期開始時における単位乾物重あたり呼吸速度（Respiration rate per unit dry weight, RPW）は，直前の明期の光強度に影響されるが，明期の長さとは関係なかった．暗期開始後 RPW は時間とともに低下し，その後上昇するが，極小となった時の RPW は明期の長さによって異なり，明期の長さが短いほど低い値を示した．加えて，RPW が一時的に上昇した時の値は，光強度および明期の長さの両方に影響され，光強度と長さの積である積算光強度との間に直線的な関係があった．窒素供給を停止した個体では，前述のような RPW に対する明期の長さの影響はまったくみられなかった．

以上より，暗期における呼吸速度の経時変化は二つの相より成り，一つは暗期開始直後に見られ，明期の光強度の影響を受けること，他の一つは，それ以降に見られ，明期の積算光強度の影響を受けることがわかった．したがって，呼吸速度は二つの異なる生理過程によって制御されていると結論された．
キーワード：呼吸，呼吸の経時変化，ダイズ，窒素欠乏，光強度，明期の長さ．

In the previous paper[6] we reported that the respiration rate per unit dry weight (RPW) of young and nitrogen-supplied soybean plants showed a temporary increase around 6 hours after the initiation of the dark period, which was called the midnight rise of respiration (MRR), although old or nitrogen-depleted plants did not show it. The temporary increase of respiration rate at midnight similar to our MRR was also observed in other species[1,2,5]. From these results, it could be inferred that time course changes of respiration are not

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necessarily controlled only by the level of carbohydrate. Further it was hypothesized that the behavior of RPW in the dark period was in part the reflection of the time course changes of demanding strength in plant for the respiratory energy and metabolites needed for the performance of nitrogen metabolism in plant.

On the other hand, it is well known that there is a positive correlation between light intensity or photosynthetic rate in the preceding light period and respiration rate in the following dark period[1,3,4]. Ludwig et al.[2], however, found that the respiration rate in tomato was more sensitive to changes of photosynthetic rate when it was altered by light intensity, than when altered by CO_2 concentration, even if the photosynthesis was maintained at the same rate in both cases. He concluded that light could regulate the respiration rate not only through the amount of photosynthate but also through some other factors. These results suggest that the light conditions in the preceding light period affect time course changes of respiration rate through some internal factors other than the amount of carbohydrates.

In this paper, time course changes of respiration in soybean plants were examined with special emphasis on the light conditions in the preceding light period.

Materials and Methods

Plant materials ; Soybean plants (*Glycine max* (L.), Merr. cv. Tsurunoko) were cultured with the nutrient solution, according to the method as previously reported[6], in the glass room of the Center of Environment Regulation System for Biology (CERES), the University of Tokyo. The temperature and relative humidity during the raising period, were maintained at 25/20°C (day/night) and 70% respectively. When the plants reached the flowering stage after 31 days from sowing, with the 5th trifoliate on the main stem fully expanded, they were transferred to a growth cabinet where the air temperature, relative humidity and light intensity were maintained at 25°C, 70% and 610 $\mu E \cdot m^{-2} \cdot s^{-1}$ (PAR) with 12 hours light period, respectively. After they were acclimatized to the new environmental conditions for six to nine days, different light conditions were applied to the plants according to the experimental design as shown in Fig. 1. No nodule was observed with the roots in all plants.

Experimental design ; The experiment consisted of two sets of lighting treatments. The first set consisting of five plots as from No. 1 to No. 5 in Fig. 1, was for the investigation of the effects of length of light period on the RPW. In this set, three subplots of different light intensities (610, 260, 100 $\mu E \cdot m^{-2} \cdot s^{-1}$) were included in each plot in order to investigate the combined effects of the length of light period and light intensity on the RPW. Furthermore, the subplots of the strongest light intensity in each plot involved nitrogen-depleted plants which were cultured in the nitrogen depleted sulution for 4 days. The second set consisting of four plots as No. 2 (common plot with the first set) and No. 6

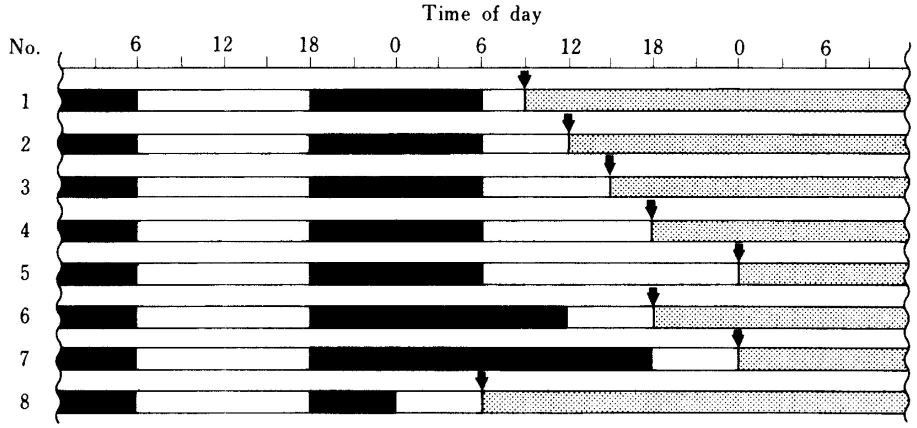

Fig. 1. Experimental design. See text for detail. ■, dark period ; □, light period ; ▒, dark period for measurement of respiration. Arrows show the start of measurerent.

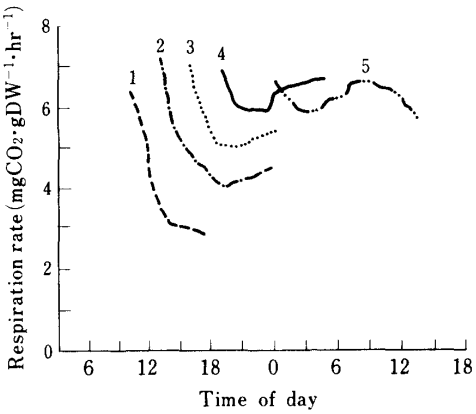

Fig. 2 Time course of respiration rate in the continuous dark. The numbers correspond to the plot numbers in Fig. 1. Light intensity in the preceding light period was 610 $\mu E \cdot m^{-2} \cdot s^{-1}$ (PAR).

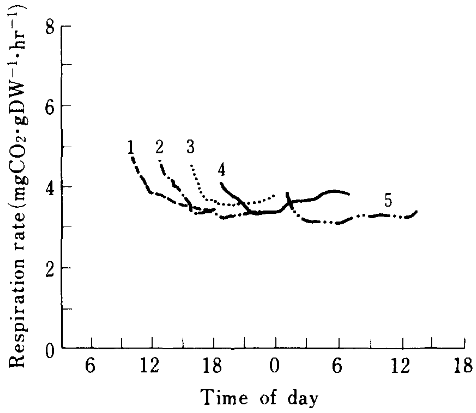

Fig. 3. Time course of respiration rate in the continuous dark with nitrogen-depleted plants. The numbers correspond to the plot numbers in Fig. 1. Light intensity in the preceding light period was 610 $\mu E \cdot m^{-2} \cdot s^{-1}$ (PAR).

through No. 8 was for the investigation of the effect of starting time of the light period with the same length on the RPW.

Measurement of respiration rate; The continuous measurements of CO_2 exchange rate in a whole plant were started at the beginning of dark period as indicated by the arrows in Fig. 1, with the measuring system as previously reported[6]. The air temperature and dew point during the measurement was 25°C and 20°C respectively.

Results

The time course changes of RPW in the plants which experienced different length of light period were shown in Fig. 2. The levels of RPW at the onset of the dark period were almost the same, indicating that the initial values of RPW were independent of the length of preceding light period. However, the time course change after the initiation step was different among the plots. The plants having experienced the longer light period showed the higher values of RPW at the bottom level, and the more evident temporary increases of RPW which was called midnight rise of respiration (MRR)[6]. When nitrogen was depleted from the nutrient solution for 4 days, the behavior of RPW changed to be flatter with less MRR, as shown in Fig. 3.

In order to elucidate further the mechanism of time course changes of RPW. CO_2 exchange rate was chased in the plants which experienced 6 hours of light period inserted at the different time of a day. RPW showed no significant difference among the plots in respect of initial values and time course changes (Fig. 4). This means that RPW changes in the same way irrespective of the initiating time of light period in a day.

The effects of light intensity on RPW are shown in Fig. 5. The higher was the light intensity in the preceding light period, the greater the fluctuation of RPW became and consequently the more evident MRR appeared. In addition, the light intensity affected the

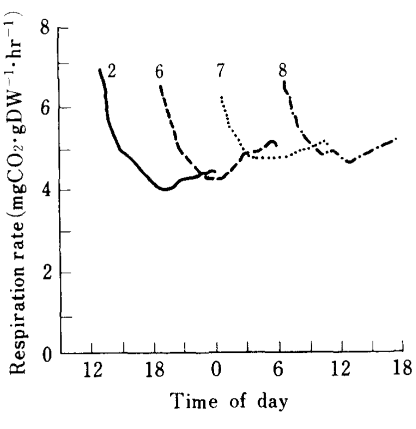

Fig. 4. Time course of respiration rate in the continuous dark. The numbers correspond to the plot numbers in Fig. 1. Light intensity in the preceding light period was 610 $\mu E \cdot m^{-2} \cdot s^{-1}$ (PAR). Length of light period was 6 hours.

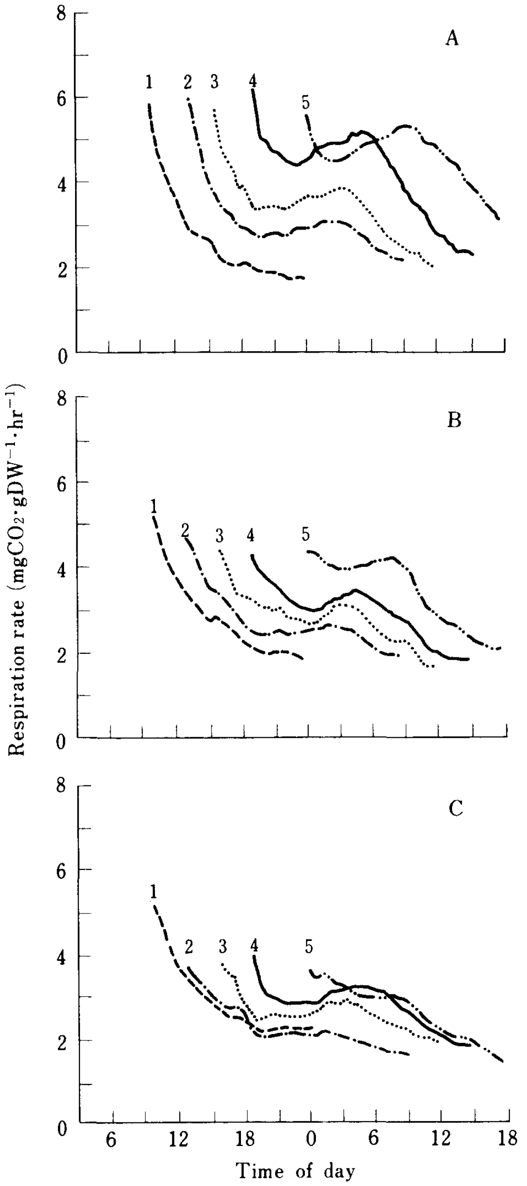

Fig. 5. Time course of respiration rate in the continuous dark. The numbers correspond to the plot numbers in Fig. 1. Light intensities in the preceding light period were 610 μE • m^{-2} • s^{-1} (PAR) (A), 260 μE • m^{-2} • s^{-1} (PAR) (B) and 100 μE • m^{-2} • s^{-1} (PAR) (C).

initial values of RPW, as shown in Fig. 6 which was originated from Fig. 5. As indicated here, when the light intensity in the preceding light period is high, the initial value of RPW in the dark is also maintained high.

Discussion

This experiment showed that the initial values of RPW in the dark period changed

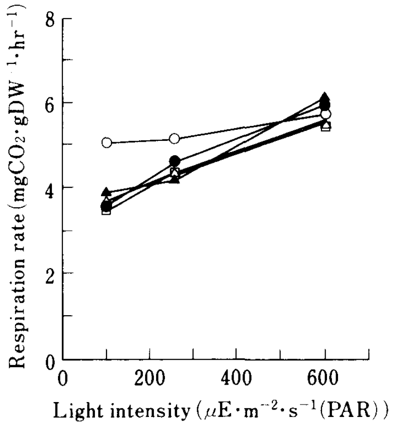

Fig. 6. The relationship between initial rate of respiration at the onset of dark period and the light intensity in the light period. The data were originated from Fig. 5. ○, 3; ●, 6; △, 9; ▲, 12; □, 18 hours in the preceding light period.

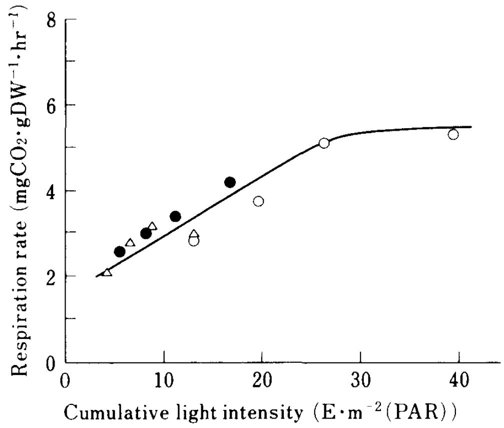

Fig. 7. The relationship between respiration rate at MRR and cumulative light intensity. The data were originated from Fig. 5. ○, 610; ●, 260; △, 100 μE • m^{-2} • s^{-1} (PAR) of light intensity in the preceding light period.

according to the intensity of the light in the preceding light period, although they were not affected by the length of the light period. McCree[3] also reported that the respiration rates immediately after the initiation of the dark period were almost the same in the plants exposed to different length of light period with the same intensity. These results suggest that a certain level of RPW should be assured at the beginning of the dark period. This paper also showed that the time course changes of RPW after the initial time were affected by length and intensity of light in the preceding light period. Fig. 7 clearly indicates this point. The peak height values of MRR, as the indicators of the magnitude of the time course changes of RPW, through all the plots kept a proportional relation to the cumulative light intensity calculated from light intensity multiplied by length of light period. From this results, we could say that time course changes of RPW during the dark period must have been destined in the preceding light period.

It might be speculated, therefore, that respiration in the dark consists of two different processes. One in the initial process working at the beginning of dark period, which is controlled by intensity but not by length of light in the preceding light period. The other in the process working after the initial one, which is dependent on both length and intensity of light. The fluctuating behavior of RPW with MRR will be involved in this process. Furthermore, it was inferred that nitrogen metabolism would be closely related to the latter process, because time course changes of RPW disappeared in the nitrogen-depleted plants[6]. Our present interest is in the relationship between respiration and nitrogen metabolism and we wish to approach there in the next step.

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