# Studies on Matter Production in Sweet Potato Plants : 2. Changes of Gross and Net Photosyntheses, Dark Respiration and Solar Energy Utilization with Growth under Field Conditions

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## 2. Changes of Gross and Net Photosyntheses, Dark Respiration and Solar Energy Utilization with Growth under Field Conditions

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To make clear the variation of the CO, balance of sweet potatoes (*Ipomoea batatas* (L.) Lam.) with growth under field conditions, canopy photosynthesis and dark respiration were measured on the same materials used in the previous paper. Canopy photosynthesis was measured using chamber method. Dark respiration in population was calculated based on the dark respiratory rates and dry weight of each plant part during the growth period. Diurnal change of canopy photosynthesis at matured stage closely correlated with that of solar radiation. The response of gross photosynthetic rate to light intensity changed with LAI increase from a saturated curve to a non-saturated one. Its highest value was $32.4\,g\,DW/m^2/day$ at the end of August. Dark respiratory rates differed with each plant part and with growth stage. The amount of gross photosynthesis (Pg) and of dark respiration (R) per day, and net production (Pn=Pg-R) increased with LAI increase, reaching a maximum in August, and then decreased gradually until November. Pn/Pg and R/Pg ratios differed with growth stage, and were 60-70 % in the former and 30-40 % in the latter during the main growth period. Pn calculated CO, balance almost corresponded to CGR measured in the field. Efficiency of solar energy utilization (Eu) also differed with each growth stage. Eu based on Pg, Pn and CGR were 1.95 %, 1.25 % and 1.35 % in mean value during the growth period, respectively.

## INTRODUCTION

In the previous paper (Agata and Takeda, 1982), we clarified the characteristics of dry matter and yield production of sweet potatoes under field conditions in relation to climatic factors. In general, dry matter production is determined by CO, balance between photosynthesis and dark respiration. Therefore, it is necessary for further analysis of dry matter production to make clear the change of canopy photosynthesis and dark respiration with growth. A lot of research from this viewpoint has been done on other crops (Takeda, 1961; Murata, 1961; Shimizu and Tsuno, 1957; Kumura and Naniwa, 1965; Kubota *et al.,* 1972; Koh and Kumura, 1973; Inanaga and Kumura, 1974), but not much research has been done into sweet potatoes. Tsuno and Fujise (1965) made the first measurement of canopy photosynthesis of sweet

potatoes. However, their measurement was made with potted population and it was not done throughout the whole growth, period.

In this investigation, canopy photosynthesis and dark respiration of sweet potatoes under field conditions were measured to elucidate the alteration of $CO_2$ balance with growth. Also the characteristics of gross and net photosyntheses, dark respiration and solar energy utilization under field condition were examined.

## MATERIALS AND METHODS

The same materials used in the previous paper (Agata and Takeda, 1982) were also used for the measurement of canopy photosynthesis and dark respiration. The relation between the light intensity and the CO, exchange (apparent photosynthesis) in canopy was periodically measured 6 times using an open system assimilation-chamber method under field conditions during the whole growth period. Diurnal change of CO, exchange in matured canopy (LAI 4.5) was also measured on September 1, 1979.

The assimilation chamber made of transparent acryl resin was designed $45 \, cm \times 45 \, cm \times 40 \, cm$, and it was put on a metalic frame. This metalic frame rested on the stolons and soil carried from another place was heaped up around the frame for preventing air leaking.  The air temperature inside the chamber was regulated letting water run on the chamber. The volume of water could be controlled.  The reduction of CO, concentration in the chamber was made up within 20 % of ordinary atmospheric condition by controlling the amount of air-supplying into the chamber with compressor.  The light intensity in the chamber was adjusted by covering it with multiple layers of cheese cloth.  The dark respiration in field condition was measured by covering the chamber with dark curtain cloth.

The photosynthetic rates expressed as gross photosynthetic rates (g DW/ $m^2$ land area/hr) adding the dark respiratory rates to apparent photosynthetic rates measured under field conditions_ The dark respiration in each part of the plant was also measured periodically using chamber method at $25 \pm 0.5°C$. Further, the temperature coefficient $(Q_{10})$ of dark respiration was measured in the range from 10°C to 30°C. All CO, gasses sampled were analysed with an infra-red gas analyzer. A factor of 0.61 was used for conversion of CO, to dry matter.

The efficiency of solar energy utilization (Eu) shows the ratio of fixed energy calculated as 3.75 Kcal (Monteith, 1966) per g of dry matter to the total amount of incident radiation.

## RESULTS AND DISCUSSION

The measured results of canopy photosynthesis and dark respiration in two cultivars (Koganesengan and Minamiyutaka) used in this experiment were almost similar. Therefore, the following results reported here are mainly
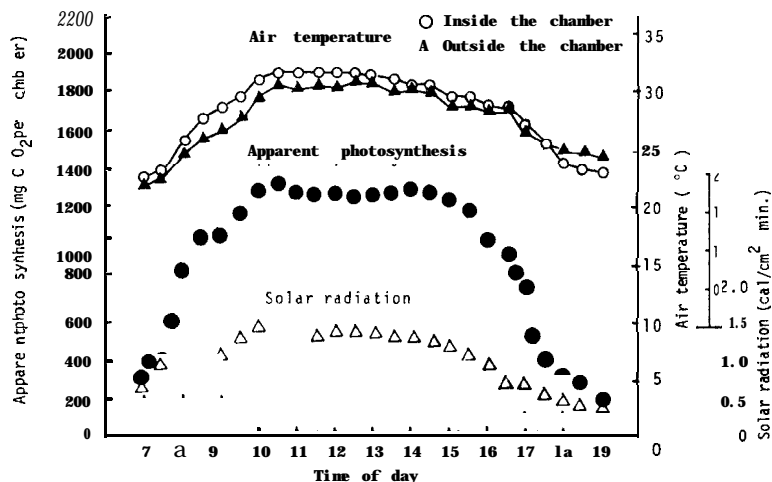
Fig. 1. Diurnal changes of apparent photosynthesis, solar radiation and air temperature on September 1, 1979 (cultivar: Koganesengan, at LAI 4.5).

those obtained with Koganesengan.

### 1. Diurnal change of canopy photosynthesis

Fig. 1 shows diurnal changes of canopy photosynthesis at LAI 4.5, air temperature (inside and outside the chamber) and solar radiation on September 1, 1979. Generally, inside air-temperature of the chamber was higher than that of the outside at each time except for the time after 18 : 00. But the difference between air-temperatures of the inside and the outside was 1.16±0. 60°C throughout the whole term of the experiment. This fact indicates that the regulation of inside air-temperature of the chamber is good for the measurement of canopy photosythesis.

The canopy photosynthesis varied with time, that is, it increased linearly until 10 : 00 and reached the maximum value at 11 : 00 and then kept a constant level until 14 : 00, and it decreased rapidly from 14 *: 00* to 19 : 00. Such a diurnal change was more similar to that of solar radiation than air temperature. The same results have been reported on other crop populations (Shimizu and Tsuno, 1956; Kumura and Naniwa, 1965; Koh and Kumura, 1973; Agata *et al., 1972).*

### 2. Changes of canopy photosynthesis to light intensity with growth

The relations between light intensity and canopy photosynthesis under field conditions are shown in Fig. 2. The gross canopy photosynthetic rate under strong light intensity increased rapidly in proportion to LAI increase from July 24 to August 23, and then it decreased gradually towards October 23 in spite of the presence of LAI above 4.0. The highest value of the gross photosynthetic rate was 5g DW/m² per hour on August 23. This value was higher cornpaired to that of Tsuno and Fujise (1965). The response of gross
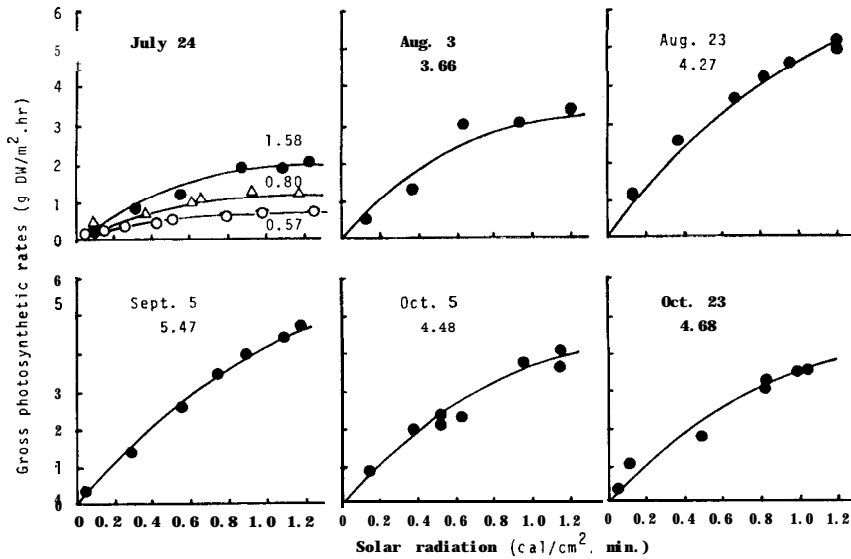
Fig. 2. Solar radiation-gross photosynthetic rate curve at different growth stages under field conditions  (numerals in figure indicate LAI values, cultivar : Koganesengan).

photosynthetic rate to light intensity showed a saturated curve in the stage of smaller LAI, but a fairly non-saturated curve in the stage of LAI above ca. 3.0. Such a result has been found in other crop populations (Takeda, 1961; Murata, 1961; Shimizu and Tsuno, 1957; Kubota *et al.,* 1972), but the light saturation point of this crop seems to be smaller than that of other crops belong to Gramineae owing to be horizontal leaf expansion type.

Fig. 3 shows the relations between LAI and gross photosynthetic rate under different light intensities.  These values were calculated from the results of Fig. 2. The gross photosynthesis increased with LAI increase under each light intensity, but its slope remarkably differed with light intensity. This indicates that effect of LAI to canopy photosynthesis varies with light  intensity.

### 3. **Dark respiration in plant**

Dark respiratory rates of each organ at several growth times are given in Table 1. These values differed with each plant part, that is, the value with leaf was the highest and the value became smaller with petiole plus stolon, root and tuberous root, in this order.  They also tended to decrease from the early stage to the latter stage of growth. The value of the whole plant was calculated from the respiratory rate and the dry weight of each plant part at the same time reported in the previous paper (Agata and Takeda, 1982). Further, the temperature coefficient ($Q_{10}$) of their rates in the range of 15°C to 30℃ was almost 1.6 in mean value.

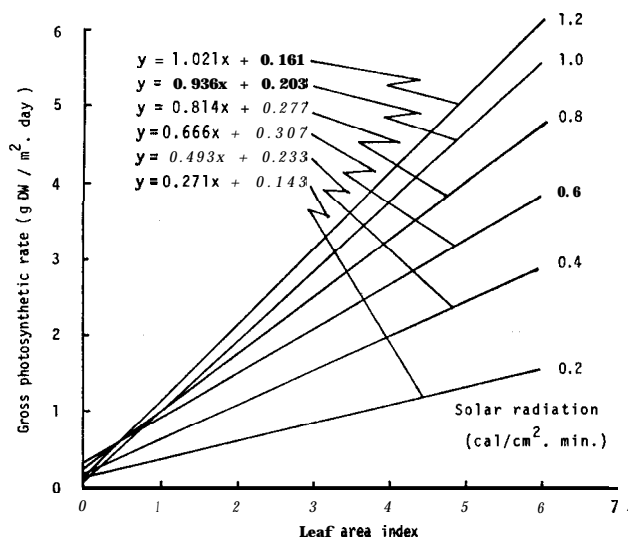### 4. **$CO_2$ balance under field conditions**

Fig. *3*. Relations between leaf area index and gross photosynthetic rate in population at various solar radiation (cultivar: Koganesengan).

Table 1. Respiratory rates of each organ in plant at different growth stages of sweet potato. The values indicate mg $CO_2$/g·hr at 25°C.

| Date | Leaf | Petiole +Stolon | Tuberous root | Root | Whole plant |
|---|---|---|---|---|---|
| July 18<br>Aug 4 | 4.68 4.49 | 3.07 3.36 | 2.09 | 2.43 5.09 | 4. 3.27 10 |
| Aug: 18 | 5.66 | 2. 19 | 1.09 | 1.03 | 2.34 |
| Sept. 3 | 1.12 | 0.67 | 0. 24 | 1.42 | 0.48 |
| Oct. 1 | 1.38 | 0.66 | 0. 20 | 1.27 | 0. 48 |

Based on the gross photosynthesis-light curve in Fig. 2, plant respiratory rate in Table 1, total dry weight and LAI, and the mean air temperature and solar radiation in each growing time reported in the previous paper (Agata and Takeda, 1982), the amount of gross photosynthesis (Pg), dark respiration (R) per unit land area per day at each growth time were computed by the method described in the senior author's previous reports (Agata *et al., 1972;* Kubota *et al., 1972).*

The variation of Pg and R with growth are shown in Table 2 and Fig. 4. Pg increased from the early stage to the middle stage of growth. And the maximum value was 32.4 g DW/m² per day at the middle of August. There-after, it decreased gradually to November. R also showed seasonal change similar to Pg. The increase of R in the first half period depended on the increase of LAI and high air temperature. On the other hand, the decrease of R in the second half was correlated with the increment of the ratio of tuberous root weight to total dry weight and the decrease of air temperature.

Net production (net photosynthesis, Pn), which is decided by Pg minus R is also shown in Fig. 4 and Table 2. Pn showed an increasing tendency
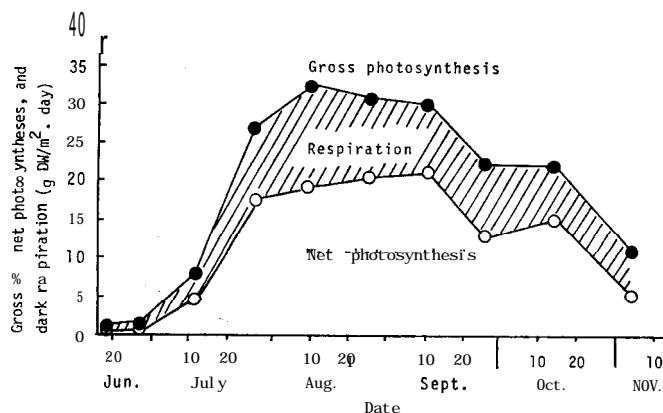
**Fig. 4.** Changes of gross photosynthesis, net photosynthesis and dark respiration during the growth period (cultivar : Koganesengan).

until the middle of September, and then it decreased gradually towards harvesting time. This pattern of Pn was more similar to that of Pg than that of R. Actually, the correlation coefficient between Pn and Pg was larger than that between Pn and R. This means that Pn depended mainly on Pg. However, it is noticed that the peak of Pn is shown in later time than that of Pg. This is the reason why the dark respiratory rate in the first half period is higher than that in the second half period.

The ratio of Pn to Pg was larger than that of R to Pg, that is, the mean ratios of the former and of the latter during the growth period were 59.3± 10.6 % and 40.7±10.7 %, respectively. However, both values differed contrastingly with each growth period. Thirty to forty % of R/Pg ratio at the middle period coincided well with Tsuno and Fujise (1965)'s data, but it is necessary to pay attention to the fact that the R/Pg ratio varies according to the growth period..

5. **Efficiency for solar energy utilization**

The solar energy utilization efficiency (Eu) based on Pg, Pn and CGR are also given in Table 2. Eu based on Pg showed about 1.95 % throughout the whole growth period, but it differed with each growth period, that is, Eu tended to increase with the increase of LAI, reaching a maximum value (3.5 %) at the end of August, and then to decrease gradually towards November. Eu based on Pn showed a similar pattern to Pg, and mean and maximum values of it were 1.25% and 2.38 %, respectively. Eu based on CGR also showed almost a similar pattern to Pn and its mean value was 1.35 %.

According to the JIBP report (Kanda, 1975), the mean Eu of rice, soybean, maize and sugar beet based on CGR during the growth period are 1.25 %, 0.72 %, 1.34% and 1.34 %, respectively. While, Eu of sweet potatoes, 1.35 %, in this experiment was close with that of maize and sugar beet and it was higher than that of soybean in spite of the same broad-leaf plant type. As for the reason of this result, the following factors may be considered: 1) Sink effect for photosynthesis of root crop is large. 2) Yield productive

**Table 2.** Changes of crop growth rate (CGR), the amount of gross photo-synthesis (Pg), dark respiration (R) and net photosynthesis (Pn) per day, and the ratios of Pn/Pg, R/Pg and Pn/CGR, and efficiency for solar energy utilization (Eu) based on Pg, Pn and CGR during the growth period. Eu shows the ratio of fixed energy calculated as 3.75 Kcal per g of dry matter to the total amount of incident radiation.

| Items | June 11 June 22 | June 23 July 4 | July 5 July 21 | July 22 Aug. 2 | Aug. 3 Aug. 20 | Aug. 21 Sept. 4 |
|---|---|---|---|---|---|---|
| CGR g/m²·day | 0.45 | 0.71 | 4.88 | 18.59 | 22.91 | 18.13 |
| Pg g/m²·day | 1.10 | 1.87 | 8.00 | 27.00 | 32.40 | 30.80 |
| R g/m²·day | 0.66 | 1.01 | 2.99 | 9.07 | 13.09 | 9.82 |
| Pn g/m²·day | 0.44 | 0.86 | 5.01 | 17.93 | 19.31 | 20.98 |
| Pn/Pg % | 40.0 | 46.0 | 62.6 | 66.4 | 59.6 | 68.1 |
| R/Pg % | 60.0 | 54.0 | 37.4 | 33.6 | 40.4 | 31.9 |
| Pn/CGR % | 97.8 | 121.1 | 102.7 | 96.4 | 84.3 | 115.7 |
| Eu of Pg %  Eu of Pn % | 0.07 16 | 0.29 0.13 | 0.78 0.49 | 2.02 1.34 | 2.88 1.72 | 3.50 2.38 |
| Eu of CGR % | 0.07 | 0.11 | 0.47 | 1.39 | 2.04 | 2.06 |

| Items | Sept. 5 Sept. 19 | Sept. 20 Oct. 4 | Oct. 5 Oct. 24 | Oct. 25 Nov. 14 | Mean |
|---|---|---|---|---|---|
| CGR g/m²·day | 27.13 | 13.21 | 17.63 | 5.19 | 12.88±9.01 |
| Pg g/m²·day | 30.00 | 22.00 | 22.00 | 11.00 | 18.62±11.49 |
| R g/m²·day | 8.33 | 8.20 | 6.81 | 5.91 | 6.59±3.79 |
| Pn g/m²·day | 21.67 | 13.80 | 15.19 | 5.09 | 12.03±7.94 |
| Pn/Pg % | 72.2 | 62.7 | 69.0 | 46.3 | 59.3±10.6 |
| R/Pg % | 27.8 | 37.3 | 31.0 | 53.7 | 40.7±10.7 |
| Pn/CGR % | 79.9 | 104.5 | 86.2 | 98.0 | 98.7±12.6 |
| Eu of Pg %  Eu of Pn % | 2.76 2.00 | 2.79 1.75 | 2.51 1.73 | 0.18 3.84 | 1.25±1.95 0.77 1.11 |
| Eu of CGR % | 2.50 | 1.67 | 2.01 | 0.86 | 1.35±0.85 |

period of root crop is very long.

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