

Recent Studies and Problems of Photosynthesis of Tea Plant

By SHINSUKE SAKAI

Crop Division, National Research Institute of Tea

Analysis of physiological mechanisms determining growth and yield of plucked shoot of tea plant from the standpoint of photosynthesis and dry matter production is important for improving crop management as well as to establish methods of early selection for high yield.

Tea plants differ from other crops with various characters: They are perennial ever-green arboreous plants and leaves which are photosynthesizing are harvested. They have particular productive structure (spatial distribution of leaves and stems and distribution of light within and outside of plant community) caused by the practice of plucking and pruning. Therefore, it seems that photosynthetic characteristics might also be different from other crops.

In the present paper, diurnal and seasonal fluctuation of photosynthesis of matured tea plants growing in field, photosynthesis under the shade culture, and some related problems are described.

Method for measuring photosynthesis

Photosynthesis and respiration were measured using detached shoots, potted young plants which were not yet pruned, and mature plants growing in field at the stage of plucking by means of assimilation chamber method of air-flow type⁸⁾. Plant material was placed in the assimilation chamber with air flow from air-inlet to air-outlet.

Differences in CO₂ concentration of air between the inlet and outlet was multiplied by

the rate of air supply to obtain the apparent photosynthetic rate.

The CO₂ concentration was determined at first by the electro-conductivity method but later by the infrared gas analyzer.

Shape and size of the assimilation chamber were adjusted to suit samples of various size. Supply and flow of air in the chamber were also adjusted to keep the chamber at nearly the same one as natural condition. The chamber was equipped with a water-cooling unit to control the temperature.

Preliminary measurement of detached shoots showed no bad influence of detaching provided that attention was paid to the time of detaching and water supply during the measurement⁹⁾.

Diurnal change of photosynthesis in fields

Fig. 1 shows examples of the diurnal change in an apparent photosynthetic rate of young and mature plants at various stages in a year^{2), 3), 5)}. The photosynthetic rate showed a sudden rise or fall at the time of faint light in the morning or evening owing to the remarkable change in light intensity, while it showed relatively small changes in the day time. As a result, the diurnal curve looks like a trapezoid. Sometimes, however, a midday depression was observed under conditions of high light intensity.

An increase of light intensity caused a depression of apparent photosynthetic rate because of an increased respiratory rate due to the rise of temperature inside the chamber.

Like other plants, tea plants show the

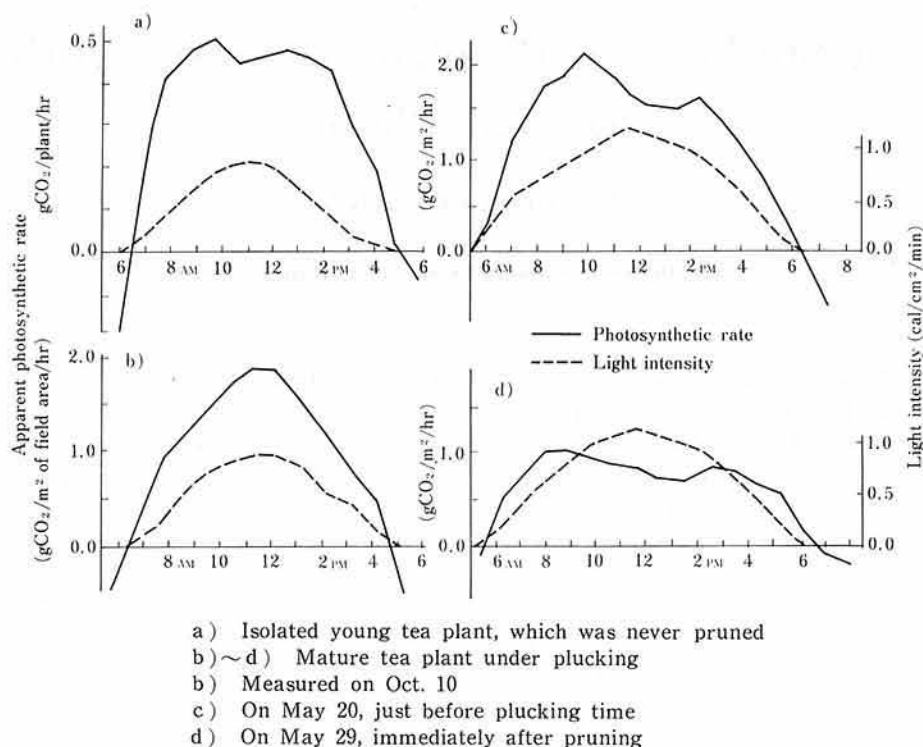


Fig. 1. Diurnal changes of apparent photosynthetic rate of tea plant

doubling of respiratory rate for every 10°C increase in temperature. The Q_{10} value was 2.25 (Fig. 2). Therefore, in order to eliminate the effect of respiration varying with temperature, "true photosynthesis" was calculated by using dark-respiration with temperature corrections.

Relations between light intensity and true photosynthesis are shown in Fig. 3. Light-

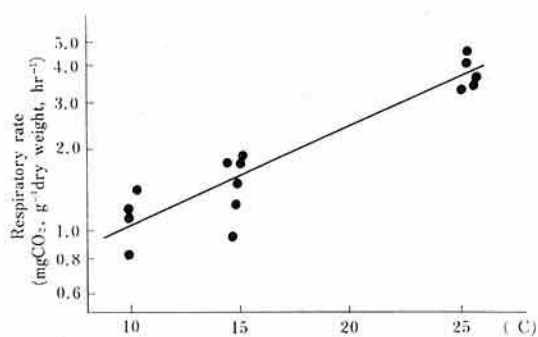


Fig. 2. Relation between temperature and respiratory rate of tea leaf

photosynthesis curves represented hyperbola. However, light-saturation points are different with materials: at about 30 klux with detached shoots, at $0.5 \text{ cal}/\text{cm}^2/\text{min}$ (approx. 37 klux) with young plants or mature plants soon after pruning, and higher than 1 cal with normal mature plants.

Such differences in light-saturation seems to be caused by the differences of plants architecture in receiving light. Sparsely arranged leaves of young plants reached a light-saturation under lower light intensity due to less mutual shading, whereas the very dense leaf layer (about 90% of leaves are distributed within 10 cm depth from the plucking surface) of mature plants inhibited light penetration. At the stage of new shoot development, the leaf layer increases its density and depth, resulting in a disappearance of light-saturation (the higher the light intensity, the greater is the photosynthetic rate). On the other hand, the pruning reduces leaf layer, making greater light penetration possible.

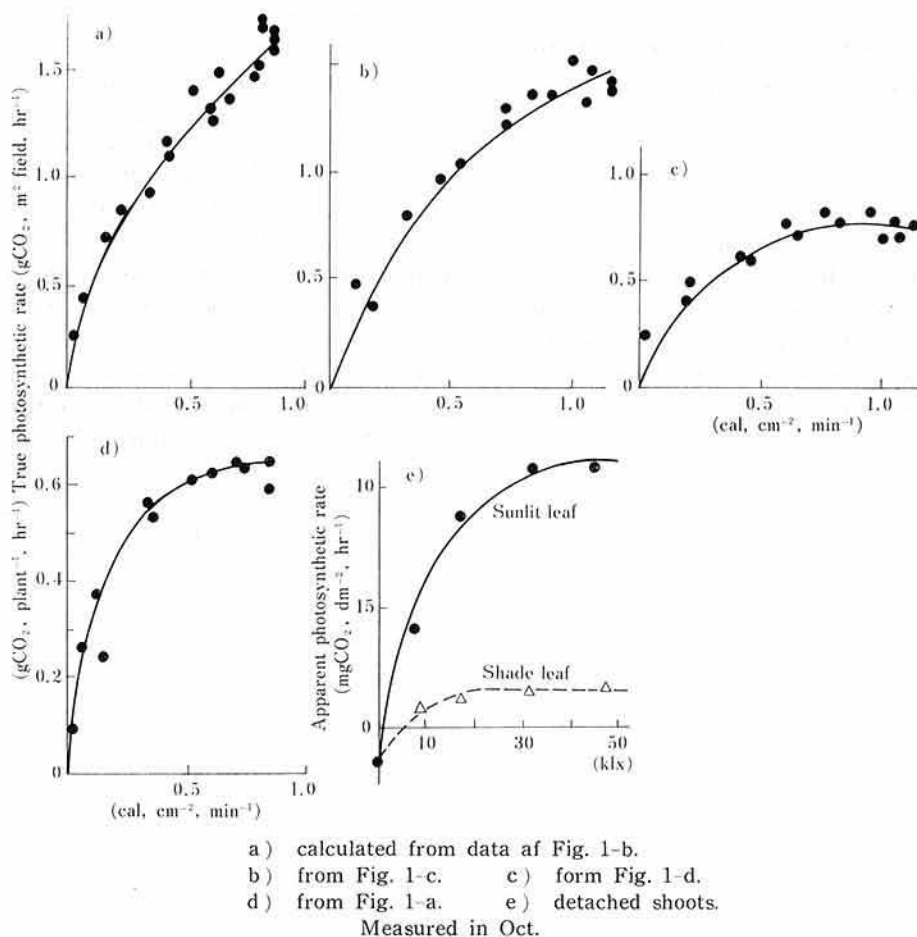


Fig. 3. Relation between light intensity and true photosynthetic rate of tea plant

Under a same light intensity, the true photosynthesis of mature plants showed no apparent change in relation to temperature. Therefore, the midday depression observed with apparent photosynthesis can be explained by the temperature-effect on respiration⁵⁾. As shown in Fig. 4, apparent photosynthesis decreases with higher temperature, whereas true photosynthesis does not, within a range of 20–35°C.

The facts that true photosynthesis is slightly higher in the morning than in the afternoon even at a same light intensity, and that the midday depression takes place in true photosynthesis soon after pruning, which causes old shade leaves inside the bush to be exposed

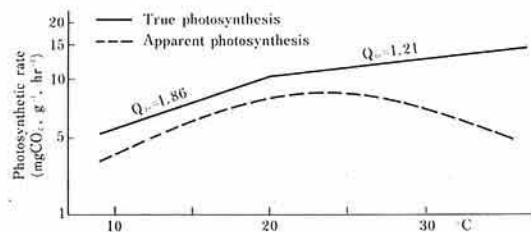


Fig. 4. Relation between leaf temperature and photosynthetic rate of tea leaf

to light, are suggestive of some other factor or factors involved in photosynthesis. Physiological factors such as water content of leaves and stomatal aperture may be involved. For the full utilization of solar energy, solution of these limiting factors will be needed.

Seasonal change of photosynthesis of mature plants in fields

Photosynthesis of mature plants already at the plucking stage was measured from season to season^{3),5)}. The result is given in Fig. 5.

The maximum photosynthetic rate and net production showed high values at the growing period of shoots from summer to autumn, except immediately after the pruning, but the values decreased in winter when plant growth ceased. In a season of shoot growing, these values were low at the time of bud opening, increased with shoot growth and declined again after plucking.

Such seasonal changes depend not only on the climatic conditions such as light intensity, duration of sunshine and air temperature and

the change of leaf quantity but also on the photosynthetic capacity of leaves.

From measurements of photosynthesis of each phylotaxis of growing shoot and the successive measurement of leaves with different time of bud opening, it was recognized that leaves just expanded have low photosynthesis and high respiration rate but the photosynthetic rate increases gradually, reaching a peak, and then declines with aging¹⁰⁾ (Table 1).

Photosynthesis of leaves developed in summer to autumn, decreased in winter, but increased at the first flushing period of the following spring. Up to about 80% of the rate in the previous autumn, and then declined again when the first flushing period was over⁹⁾ (Fig. 6).

Although such changes seem to be associated

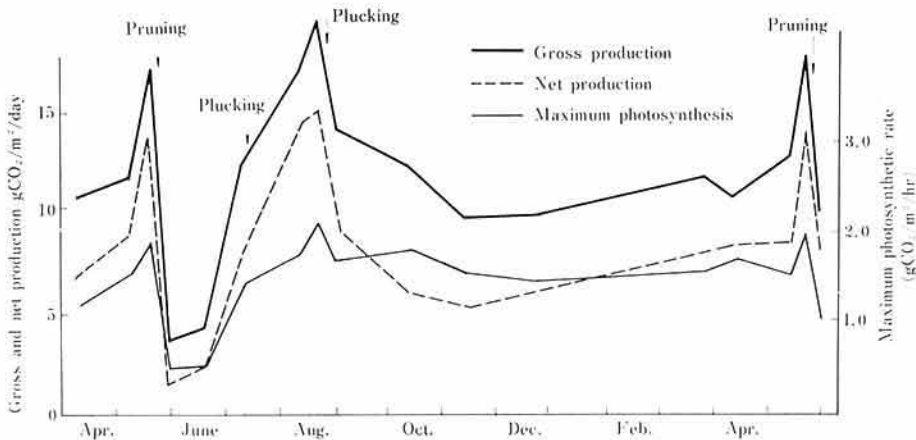


Fig. 5. Seasonal change of photosynthesis of mature tea plant

Table 1. Seasonal changes of photosynthetic rate of tea leaves as affected by varieties and the time of bud opening

Variety	(mg CO ₂ , dm ⁻² , hr ⁻¹)														
	June		Aug.			Oct.			Dec.			Feb.		Apr.	
	I	I	II	I	II	III	I	II	III	II	III	II	III		
Yutakamidori	6.31	7.99	8.11	6.68	7.66	10.13	5.42	7.97	9.40	1.33	1.26	7.90	6.14		
Yabukita	6.18	9.47	9.78	3.43	4.75	8.43	2.95	4.79	6.29	2.49	3.23	5.64	5.91		
Hatsumomiji	5.09	6.93	6.55	4.69	7.99	5.52	5.32	6.16	5.85	0.88	0.90	4.64	4.59		
Asatsuyu	5.26	4.84	5.92	3.25	4.58	7.73	4.14	4.44	5.90	1.91	2.18	4.39	5.80		

Note: I = 1st growing period II = 2nd growing period III = 3rd growing period

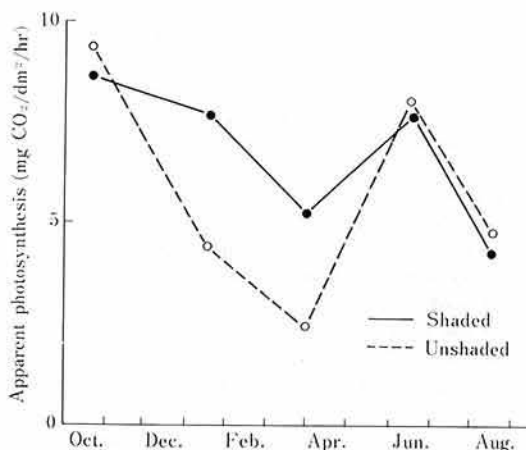


Fig. 6. Effect of shading on seasonal changes of photosynthetic rate of tea leaf

with changes of respiration rate, leaf areal weight, total nitrogen content and chlorophyll content, no close correlation was found between them throughout the whole growth period of leaves^{9,10}.

With respect to varietal difference in photosynthetic capacity, some differences were recognized in maximum rate and duration of the maintenance of high capacity. Among varieties of good viability higher values were found¹⁰.

Based on the seasonal changes in photosynthesis, total carbohydrate content of mature plants⁷ and yields of tea, the following facts were found: (1) in winter, although photosynthesis is less than in other seasons, net production still continues and carbohydrate is reserved in plants, (2) in autumn, although light intensity is less than that in summer, the photosynthetic rate per unit light intensity is high and net production is large, (3) from April to June, photosynthesis becomes active owing to the recovered photosynthetic capacity of overwintered leaves, but, as net production is not enough to compensate the loss by harvest, total carbohydrate content decreases remarkably, and (4) it is necessary to maintain sufficient quantity of leaf in autumn—spring season, to accumulate carbohydrate reserve and to promote photosynthesis in the spring season in order to increase the spring

yield which is important commercially and to maintain the viability of trees.

Photosynthesis of tea plants under shade culture

In Japan, tea plants are often cultured under the shade with 10–15% of light permeability, for the purpose of improving quality of plucked leaves and protecting leaves from cold and frost.

Photosynthetic rate was measured with detached shoots from the shade culture. In the summer season, it was found that the lower the light permeability or the longer the period of shade the lower the photosynthesis was (Table 2). On the contrary, in the autumn—

Table 2. Changes in photosynthetic rate under shading condition

Light intensity as % full sun	(mg CO ₂ , dm ⁻² , hr ⁻¹)				
	Over-wintered leaf			Fresh leaf	
	Apr. 17	Apr. 27	May 8	Apr. 28	May 7
100	5.93	5.46	4.20	4.62	5.47
50	4.58	5.04	3.44	4.62	5.32
10	2.46	2.04	1.99	2.95	4.15

winter season, photosynthetic rate was higher with the shade culture than unshaded one (Fig. 6), due to the fact that the shade protected plants from cold damage^{8,9}.

Effect of the shade on the photosynthesis of whole plants was more remarkable. Under 25% of light permeability, both young shoot weight and carbohydrate content were markedly reduced, though the reduction in the former was not apparent under 50% light permeability.

Barua reported the usefulness of shade trees in northeast India and discussed the reasons. However, under a temperate climate of Japan, the shade in the summer season has no advantage on growth, except its effect on tea quality. Advantage is found only in protecting wintering leaves from cold damage.

Future problems related to photosynthesis of tea plants

In addition to the daily and seasonal variations of photosynthesis of mature plants growing in field, and related factors such as light intensity, temperature, plant architecture for receiving light, and photosynthetic capacity of single leaf, all of them were reported in this paper, studies have been made on the light quality, CO₂ concentration, chemical component of leaves, soil moisture, and varietal difference in relation to photosynthesis.

CO₂ compensation point was found at about 70 ppm (unpublished), and this high value suggests that tea plants might be a C₃-plant, which performs light-respiration.

Further studies will be needed on light-respiration, enzyme activities, and characteristics of leaves such as stomatal diffusion resistance as related to climatic factors.

With plants growing in fields, further studies are needed on varietal differences and types of bush in relation to light utilization. Barua reported that the angle of leaves influences photosynthesis. Though it is uncertain that to what extent the varietal difference in leaf angle does exist in Japanese tea garden with shear plucking, these problems will need further studies, including a possibility of modifying bush types.

References

- 1) Barua, D. N.: Light as a factor in metabolism of the tea plant (*Camellia sinensis* L.). ed. by Luckwill, L. C. & Cutting, C. V., *Physiology of Tree Crops*, London, Academic Press Inc., 307-322 (1970).
- 2) Harada, S. et al.: Studies on photosynthesis of tea plant. II. On the diurnal and seasonal changes of the assimilation rate of tea plant. *Study of Tea*, No. 17, 1-6 (1957) [In Japanese, English summary].
- 3) Harada, S. et al.: Studies on the assimilation of carbon in the plant. III. On the assimilation of carbon in mature tea garden. *Study of Tea*, No. 20, 6-9 (1959) [In Japanese, English summary].
- 4) Harada, S. et al.: Studies on photosynthesis of tea plant. IV. Differences of photosynthesis by layer of leaves in mature tea garden. *Study of Tea*, No. 22, 1-5 (1960) [In Japanese, English summary].
- 5) Harada, S. et al.: Studies on the assimilation of carbon in tea plant. V. On the assimilation of carbon in mature tea garden. *Study of Tea*, No. 25, 1-10 (1961) [In Japanese, English summary].
- 6) Nakayama, A. et al.: Studies on photosynthesis in tea plant, V. On photosynthesis in shade culture. *Proc. Crop. Sci. Soc. Japan*, 34, 514 (1966) [In Japanese].
- 7) Nakayama, A.: Changes of carbohydrate and nitrogen compounds with growth in tea plant. *JARQ*, 6(2), 97-101 (1971).
- 8) Sakai, S. et al.: Studies on the assimilation of carbon in tea plant. VI. On the apparatus for measuring gas-exchange by infrared gas analyzer, and examination of some problems on measurement of gas-exchange with the apparatus. *Study of Tea*, No. 31, 10-22 (1965) [In Japanese, English summary].
- 9) Sakai, S. et al.: Studies on dry-matter production in tea plant. II. Effect of shading and leaf picking on the matter production. *Proc. Crop. Sci. Soc. Japan*, 38, suppl. 2, 45-46 (1969) [In Japanese].
- 10) Sakai, S.: Varietal difference of matter production in tea plant. ed. by the research group for the breeding of tree crops, *Breeding of Tree Crops*, Tokyo, The Government Forest Experiment Station, 229-251 (1973).