THE JOURNAL OF AGRICULTURE
OF THE UNIVERSITY OF PUERTO RICO

Issued quarterly by the Agricultural Experiment Station of the University of Puerto Rico, for the publication of articles by members of its personnel, or others, dealing with any of the more technical aspects of scientific agriculture in Puerto Rico or the Caribbean Area.

Vol. XLVI July 1962 No. 3

Effect of Light Intensity on the Rate of Apparent Photosynthesis in Coffee Leaves

Marco A. Tió[1]

INTRODUCTION

The relation between photosynthesis and light intensity has been a subject of extensive investigation by many researchers (*1,2,3,4*)[2] who have determined the effects of different intensities of light upon the maximum rate of photosynthesis for numerous plants.

Rabinovitch (*4*) presented a number of curves illustrating light-photosynthesis effects which show conclusively that intensity is of major importance.

Bohning *et al.* (*1*), in a more recent investigation, reported that the rate of apparent photosynthesis was different in "sun-loving" and in "shade-loving" plants.[3] It was shown that, for eight sun-loving species, light-saturation values and compensation points ranged between 2,000 to 2,500 and 100 to 150 foot-candles, respectively, and that for the shade species light-saturation was reached at a maximum of 1,000 foot-candles in some species and as low as 400 to 500 foot-candles in some others.

Popp (*3*) found that, in sun-loving plants, the rate of accumulation of the products of photosynthesis was greater with increases in light intensity up to an optimum point, and that further increases in light intensity beyond this resulted in reduction of the rate. In shade-adapted plants the pattern of behavior under the same conditions was similar, except that the optimum was found to be at a point much lower than for the sun-loving plants.

In his recent book Wellman (*6*) has reviewed personal observations and experimental studies from many workers pertaining to sun- and shade-grown coffee. He pointed out that Arabica coffee was first planted in the sun and that growing in the shade was a later, more modern practice.

[1] Associate Phytophysiologist, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P.R.

[2] Italic numbers in parentheses refer to Literature Cited, p. 166.

[3] The terms "sun-loving" and "shade-loving" refer to plants that grow well, or best in the sun or in partial shade, respectively. Another way of saying this would be "sun-adapted" and "shade-adapted."

The coffee tree of the species *Coffea arabica* L. is often considered a shade-adapted plant, but it appears from observations that it has a light-saturation capacity that might place it either among the sun-loving or the shade-loving plants. This is particularly true for the variety Bourbon, Choussy; that was used in these experiments. This variety has long been grown in Brazil and many other countries with no shade at all.

The purpose of the present investigation was to determine light-saturation values and the maximum rate of photosynthesis of Bourbon coffee trees in an effort to establish the optimum light intensity for the photosynthetic function of this plant.

MATERIALS AND METHODS

The instrument used for measuring the photosynthetic rate of attached coffee leaves was an infrared gas analyzer. The set-up for the treatments is presented in figure 1 and consisted of a glass chamber placed over a steel plate 12 x 12 x 1/16 inches in size. This was painted white to reflect the light. It had underneath, and soldered to it, a copper-tubing coil 1/4 inch in diameter through which refrigerated water was circulated to lower the temperature inside the chamber.

Illumination was provided by four 300-w. internal reflector lamps placed above a glass water bath with a cooling coil in it so arranged as to leave a central unobstructed path for the light. This worked as a heat filter and had 3 inches of water in it constantly.

The different light intensities were obtained by lowering or raising the lamps which were focused to illuminate the center of the leaf chamber.

The temperature inside the chamber was kept at 20° ± 0.5° C. This was achieved by circulating water through the coils of the steel base of the chamber. This water was cooled to 3° C. in an insulated 15-gallon tank in which the cooling unit was immersed.

The refrigerated water was pumped from the tank by means of an immersion pump coupled to a thermocap relay set at 20.5° and 19.5° C., respectively. This system and the fast response of the infrared gas analyzer to the presence of CO_2 made it possible to maintain the temperature of the leaves nearly constant. A thermistor probe located under the leaf inside the chamber continuously indicated the temperature of the air kept circulating around the leaf. The air circulated through the system at a rate of flow of 1 l. per minute.

The coffee plants used were 8-month-old seedlings of the Bourbon variety of Arabica coffee grown in a greenhouse in 12-inch clay pots containing a soil mixture (2/3 soil: 1/3 filter-press cake). An equal amount of water was applied daily to each plant. Every 21 days the plants were sprayed with fungicides and insecticides to check diseases and insects.

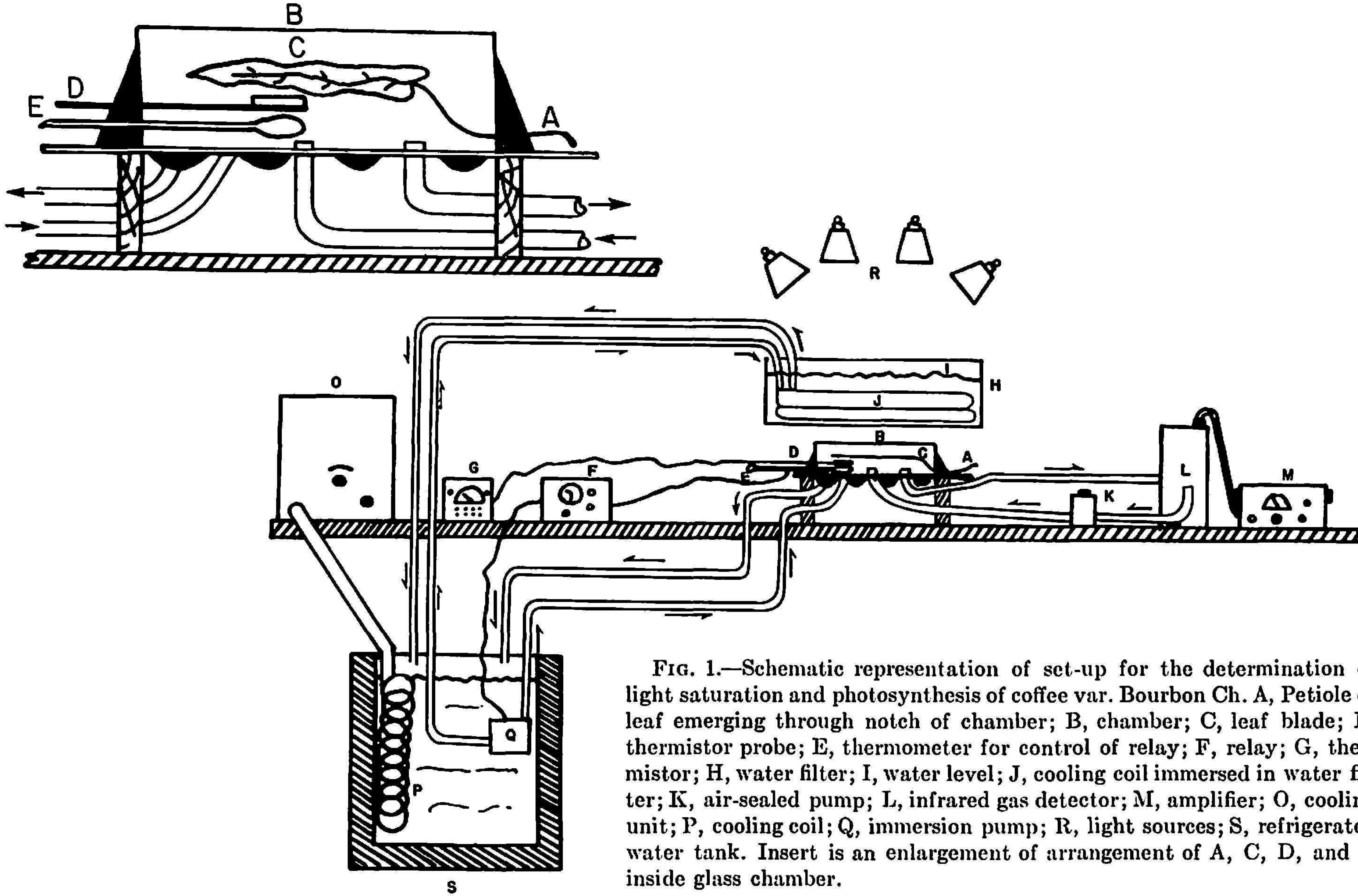

FIG. 1.—Schematic representation of set-up for the determination of light saturation and photosynthesis of coffee var. Bourbon Ch. A, Petiole of leaf emerging through notch of chamber; B, chamber; C, leaf blade; D, thermistor probe; E, thermometer for control of relay; F, relay; G, thermistor; H, water filter; I, water level; J, cooling coil immersed in water filter; K, air-sealed pump; L, infrared gas detector; M, amplifier; O, cooling unit; P, cooling coil; Q, immersion pump; R, light sources; S, refrigerated water tank. Insert is an enlargement of arrangement of A, C, D, and E inside glass chamber.

A specific method was followed in determining the rate of CO_2 fixation. Leaves from different positions on the plant were laid flat, one at a time, in the metal base already described. A round glass chamber 6 inches in diameter and 1 inch high, with two notches in its opposite sides, was placed over the leaf, taking care that the petiole emerged through one of the notches, and the leads of the thermistor probe and the thermocap relay thermometer through the other. The chamber was then sealed all around with modeling clay. Tests were performed for the detection of leaks.

Carbon dioxide was introduced inside the system by means of a calibrated syringe and a needle puncturing through a pure gum tubing having a $3/32$-inch wall which connected the chamber to the analyzer. The whole system had a volume of 487 cc. The time registering the drop to a known concentration of CO_2 in the system was recorded by means of a stopwatch. The selected range of drop in the galvanometer of the analyzer was from 3.25 to 2.25 ma. which represents, in the calibration curve expressly worked out for this experiment, a drop in concentration of 129.9 p.p.m. of carbon dioxide. The time required by the leaf to consume these 129.9 p.p.m. of CO_2 was measured six times for each of the different intensities of light used in this investigation. The values obtained in the six repeated readings were practically the same and their average is reported as the value corresponding to the particular intensity.

The leaves were detached after the final measurement and photographed on a piece of Ozalid black-line, lightweight paper, and the area determined from the contact photograph using a planimeter. The volume of the leaf was determined by immersion in a 25-cc. graduated cylinder and then deducted from the volume of the system as were also deducted the volumes of the thermistor probe and the thermometer of the thermocap relay.

RESULTS AND CONCLUSIONS

The results obtained in this investigation show that the leaves of Arabica coffee of the variety Bourbon reach their light-saturation value at an intensity of about 2,000 foot-candles.

In figure 2 a light curve for coffee is presented in which the span of the plateau of the curve indicates that these leaves reach their maximum apparent photosynthesis near the 2,000 foot-candle intensity. After attaining that level they are able to maintain it up to an intensity of about 6,000 foot-candles, after which the efficiency of the leaves to utilize CO_2 declines sharply with further increases in light intensity.

Table 1 shows the numerical values representative of the light curve of figure 2. They correspond to a leaf of an area of 0.661 dm^2. The values are reported in micrograms of CO_2 fixed per square decimeter of leaf per hour.

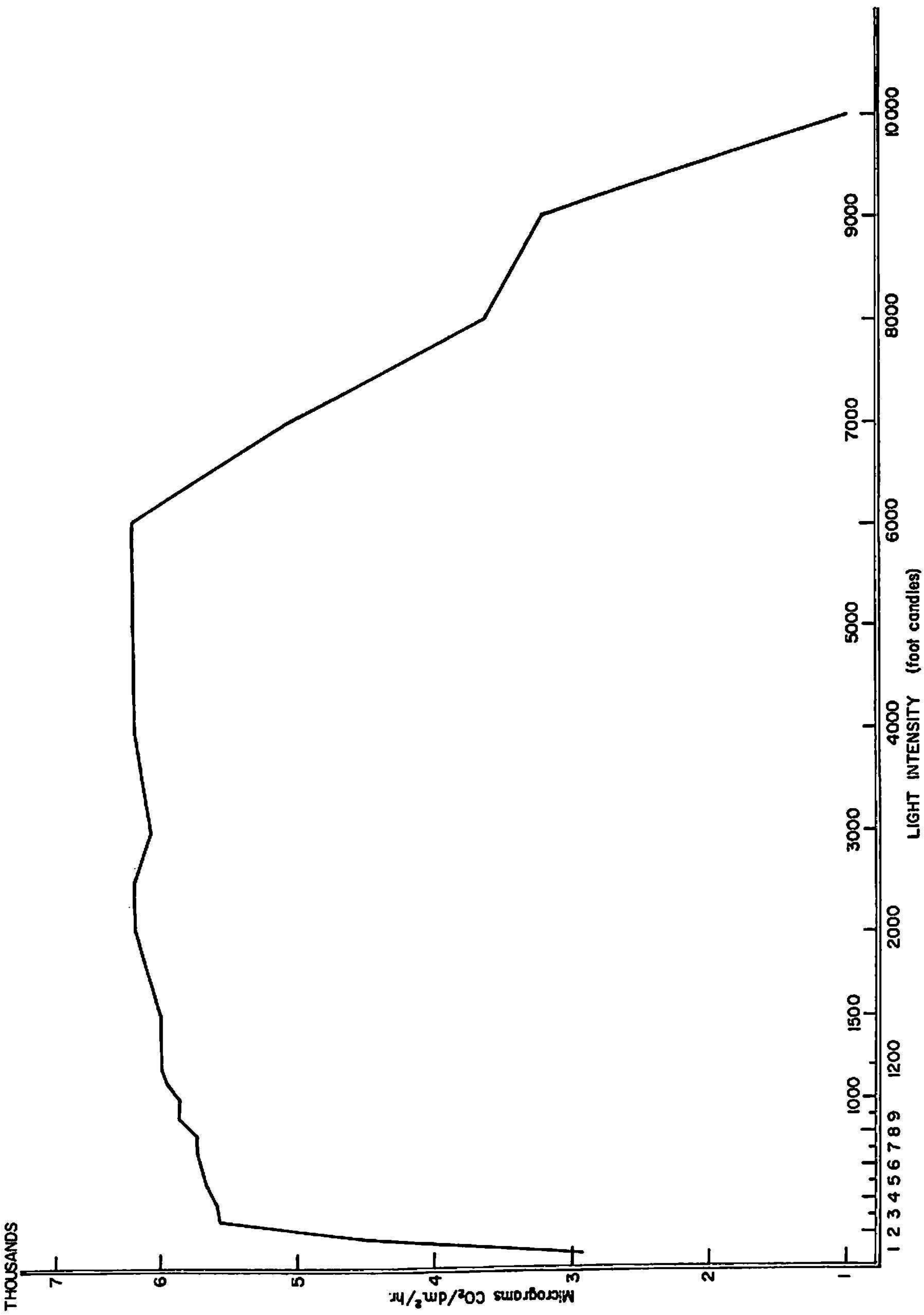

FIG. 2.—Light-saturation curve for coffee var. Bourbon, Ch.

The calculations of the photosynthetic efficiency for each light intensity correspond to the following single equation: $A = 3{,}600/t \times 1/L \times C$ where t represents time in seconds necessary to consume a known amount of CO_2, C is the amount of CO_2 in the system, and L is the area of the leaf.

It is interesting to point out that the value obtained for the light-saturation of the leaves treated in this experiment is but little above the highest

TABLE 1. *Photosynthetic efficiency of 1 leaf*[1] *of* **Coffea arabica** *var.* Bourbon, Ch. *at different light intensities*

Lighti ntensity (foot-candles)	Time	Photosynthetic efficiency
	Seconds	*μgCO/dm.²/hr.*
100	240	2,941
200	155	4,549
300	127	5,557
400	127	5,569
500	125	5,647
600	124	5,684
700	123	5,740
800	122	5,789
900	120	5,879
1,000	120	5,879
1,100	119	5,932
1,200	118	5,981
1,500	118	5,981
2,000	115	6,138
2,500	115	6,138
3,000	117	6,034
4,000	115	6,138
5,000	115	6,138
6,000	115	6,138
7,000	140	5,041
8,000	195	3,620
9,000	220	3,208
10,000	370	1,908

[1] Area of the leaf = 0.661 dm.^{2}; amount of CO_2 in the system = 129.9 μg. Results from tests on numerous other leaves were almost identical.

values attained for the saturation of shade-adapted plants, and at about the beginning of the range of values for the saturation of the leaves of sun-adapted plants as reported by other investigators (*1*). This could explain why the Bourbon variety of coffee does relatively well both under shade and in the open.

The maximum rate of photosynthesis obtained in this investigation was

6,138 μg of CO_2 per hour per square decimeter of leaf tissue. This value agrees with the average of the values reported for shade-adapted plants of the tropical zone, but does not agree with the average of the values for the sun-adapted plants of the same region, as reported by Stocker (*5*). It was also observed during the course of this investigation that apparently excessive light intensities may interfere with the efficiency of the leaf in the utilization of CO_2. When the leaves of coffee were exposed for 10 minutes to a light intensity of 10,000 foot-candles, a marked reduction was noticed in this utilization of CO_2, and when they were returned to an intensity of 2,000 foot-candles, the intensity at which they attained their maximum apparent photosynthesis, the reduction persisted and remained for about 8 to 10 hours.

In table 1 it may be observed that, at an intensity of 2,000 foot-candles, it took the leaf 1 minute and 55 seconds to utilize 129.9 p.p.m. of CO_2, and at 10,000 foot-candles it took the same leaf 6 minutes and 10 seconds to fix the same quantity of CO_2. When the same leaf after 10 minutes exposure to a light intensity of 10,000 foot-candles was returned to 2,000 foot-candles it took 20 minutes to consume the same 129.9 p.p.m. of CO_2.

DISCUSSION

Apparently an exposure of the leaves to high intensities of light may cause some kind of impairment to the photosynthetic mechanism. This seems to agree with the findings of Zurzicky (7) who, working with *Lemna trisulca*, reported in 1957 that there is an impairing effect of light upon the photosynthetic mechanism which in some plants begins at an intensity of 50,000 lux (4,600 foot-candles), and that in very intense light this impairment or destructive effect may cause the death of the chloroplasts and the cells after several hours of exposure. Zurzicky concluded that the inhibition of photosynthesis increases with the increase in light intensity and exposure time. He also held that, when the inhibition does not exceed 50 percent, it is entirely or to a high degree reversible.

SUMMARY

The rate of apparent photosynthesis relative to light intensity was determined for Bourbon variety of Arabica coffee.

A curve for the effect of light-saturation on apparent photosynthesis of coffee showed that saturation was reached at a maximum of 2,000 foot-candles and that maximum apparent photosynthesis was maintained up to 6,000 foot-candle intensity, after which it decreased.

Evidence is also presented to demonstrate that high light intensities may cause an impairment of the photosynthetic activity.

RESUMEN

Se determinó el grado de la fotosíntesis aparente y su relación con la intensidad de luz en cuanto a la variedad de café Borbón.

Una curva para la saturación de luz sobre la fotosíntesis aparente del café demostró que la saturación se alcanzaba a un punto máximo de 2,000 pie-bujías y que el máximo de la fotosíntesis aparente se mantenía hasta los 6,000 pie-bujías, luego de lo cual se reducía.

También se presenta evidencia para demostrar que altas intensidades de luz pueden causar una disminución transitoria de la actividad fotosintética.

LITERATURE CITED

1. Bohning, R. H., and Burnside, C. A., The effect of light intensity on rate of apparent photosynthesis in leaves of sun and shade plants, *Am. J. Bot.* **43** 557–61, 1956.
2. Emerson, R., Photosynthesis as a function of light intensity and temperature with different concentrations of chlorophyll, *J. Gen. Physiol.* **12** 623–39, 1929.
3. Popp, H. W., Effect of light intensity on growth of soybeans and its relation to the autocatalyst theory of growth, *Bot. Gaz.* **82** 306–19, 1926.
4. Rabinowitch, E. I., Photosynthesis and Related Processes, vol. **2**, p. 2088, Interscience Publishers Inc., New York, N.Y., 1951.
5. Stocker, O., Uber die assimilations bedingungen in tropischem Regenwald (Varlanfige Mitteilung), *Ber. Deutch. Bot. Ges.* **49**(5) 267–73, 1931. (As condensed in *Biol. Abst.* **8**(1), entry 235, 1934.)
6. Wellman, F. L., Coffee Botany, Cultivation, and Utilization, Leonard Hill, London, England, 488 pp., 1961.
7. Zurzicky, J., Dzialanie destrukcyine silnego swiatla na aparat fotosyntetyczny, summary in English, *Acta Societatis Bot. Poloniae* **25**(1) 157–75, 1957.