

# Photosynthesis of individual leaves in a coffee plant

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**ABSTRACT.** The great variability in income irradiance over a plant canopy makes difficult the comparison of photosynthesis rates among leaves in a plant and their integration. In this study, photosynthetic rates of ten different leaves of a coffee plant were obtained during a day. The daily variation in photosynthetic rates showed a peak between 7:00 h and 9:00 h with higher values measured for the leaves positioned at the sunrise direction and northern orientation. Lower values were consistently observed for leaves at inner position of the plant. After 9:00 h, despite the increase in photosynthetically active radiation, photosynthetic rates decreased steadily to reach negligible values at sunset. The reductions on photosynthesis rates can also be attributed to increasing stomatal resistance. Since number of leaves is highly variable in coffee plants, those results make evident how difficult is to integrate and estimate whole plant photosynthesis by taking the average of 10 leaves.

**Key words:** *Coffea*, photosynthesis, air temperature, leaf temperature, photosynthetically active radiation, stomatal resistance.

**RESUMO. Fotossíntese de folhas individuais de um cafeeiro.** A grande variabilidade na radiação solar incidindo em uma planta dificulta a comparação e integração das taxas fotossintéticas obtidas de diferentes folhas. Neste trabalho foram medidas, durante um dia, as taxas fotossintéticas de dez folhas, localizadas em pontos representativos em uma planta de cafeeiro. Foram observadas máximas taxas entre as 7:00 e 9:00 h, sendo os maiores valores encontrados nas folhas voltadas ao nascer do sol e na orientação norte. Os menores valores foram consistentemente observados nas folhas posicionadas no interior da planta. Após as 9:00 h, a despeito do aumento na radiação fotossinteticamente ativa, as taxas fotossintéticas diminuíram constantemente até o final do dia. Estas reduções podem ser atribuídas também aos crescentes valores de resistência estomática. Uma vez que o número de folhas é altamente variável em plantas de cafeeiro, os resultados evidenciam a dificuldade em integrar e estimar a fotossíntese de uma planta inteira usando médias de medidas tomadas em dez folhas individuais.

**Palavras-chave:** *Coffea*, fotossíntese, temperatura do ar, temperatura da folha, radiação fotossinteticamente ativa, resistência estomática.

## Introduction

Among the several studies to characterize plant behavior in response to environmental conditions, photosynthesis is the most frequent in the literature due to its role on the synthesis of carbohydrate for increasing mass and developing organogenesis. Measuring photosynthesis is of interest for plant physiologists because observed data are required to understand in detail this complex biophysical process and necessary to advance scientific knowledge by developing mechanistic models.

A limitation of measuring photosynthesis with the available equipments is that they were designed for measurement of plant parts, such as one leaf or a group of few leaves. The great variability over the whole plant, mostly due to differences in income

irradiance and also physiological characteristics of each plant organ, makes difficult comparison and integration of measurements taken on plant parts. In addition, the exact position of the leaf in the plant is not clearly described in most of reports in the literature, in which the experiments are mainly conducted in greenhouse conditions, with attenuated solar radiation, or growth-chambers, with artificial light.

Early experiments on coffee plants (Nutman, 1937, cited by Cannel, 1976) showed that photosynthesis ceased at 9:00 h and restarted at 16:00 h, regardless the variation on irradiance during the day. Unlikely, Marur *et al.* (2001), measuring photosynthesis rates in the field, did not verify drastic reduction during that time interval. Kumar and Tieszan (1980) found saturated irradiance for

shaded coffee plants equal to  $300 \mu\text{mol.m}^{-2}\text{s}^{-1}$  and about  $600 \mu\text{mol m}^{-2}\text{s}^{-1}$  for unshaded plants. The authors attributed the reduction on assimilation of plants under high irradiance to leaf temperatures between 25 to  $35^{\circ}\text{C}$ , which was assumed to be high enough to decrease mesophil conductance. In fact, Fahl *et al.* (1994) observed that high irradiance did not decrease leaf photosynthesis of potted coffee plants when temperature in the chamber used to measure  $\text{CO}_2$  assimilation was maintained below  $25^{\circ}\text{C}$ . However, Morais *et al.* (2003) found significantly lower photosynthesis rates for field coffee grown under shade of guandu tree as compared to full sunlight plants.

In an attempt to characterize  $\text{CO}_2$  absorption of different leaves of a coffee plant in its natural environment, this work has as objective to demonstrate the variability in photosynthesis rate taken at different positions on the canopy.

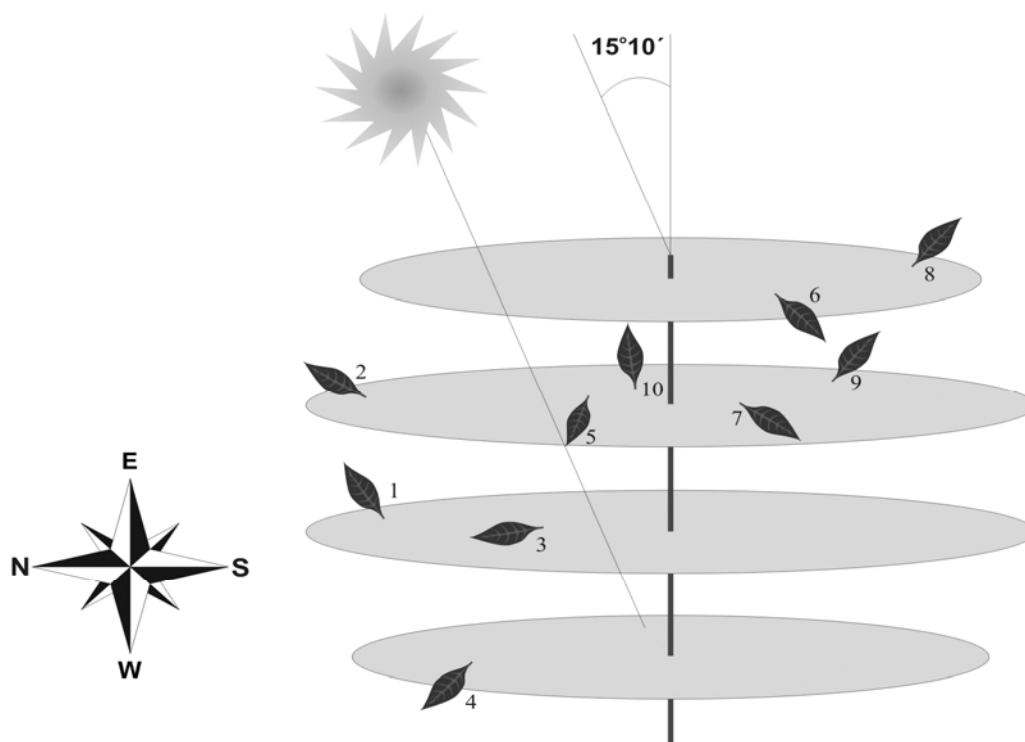
#### Material and methods

Measurements of net photosynthetic rates of individual leaves were taken from a coffee plant (*Coffea arabica* L.) of the cultivar IAPAR 59, with leaf area index equal to 5.2, 1.7 m height,

cultivated at the Experimental Station of the Instituto Agronômico do Paraná, in Londrina, Brazil (latitude  $23^{\circ} 18' \text{ S}$ , longitude  $51^{\circ} 09' \text{ W}$ ).

Ten leaves from each quartile of the coffee plant, at the positions shown in Figure 1, were chosen to represent the plant canopy. External leaves (1, 2, 4, 6, 8 and 9 in Figure 1) were at the third node from the apex of the plagiotropic stem; leaves 3 and 5 were in inner nodes at the stems and leaves 7 and 10 were at an intermediate position. According to cardinal orientation, leaves 1 and 2 were at the northern side of the plant; leaf 4 was positioned at the northwestern; leaves 5, 6 and 7 at the western; leaves 8 and 9 at the southeastern and leaf 10 at eastern.

Measurements were taken throughout a cloudless day on October 23, 2001, using a portable photosynthesis system (PPS - model LI-6200, Li-Cor, Inc., Lincoln, NE, USA) to analyze  $\text{CO}_2$  fixation by midsections of individual leaves ( $3.2 \text{ cm} \times \text{leaf width}$ ) enclosed in the one-liter chamber, during 15 seconds from the equilibrium and beginning of  $\text{CO}_2$  decreasing; natural leaf orientation was not disturbed.



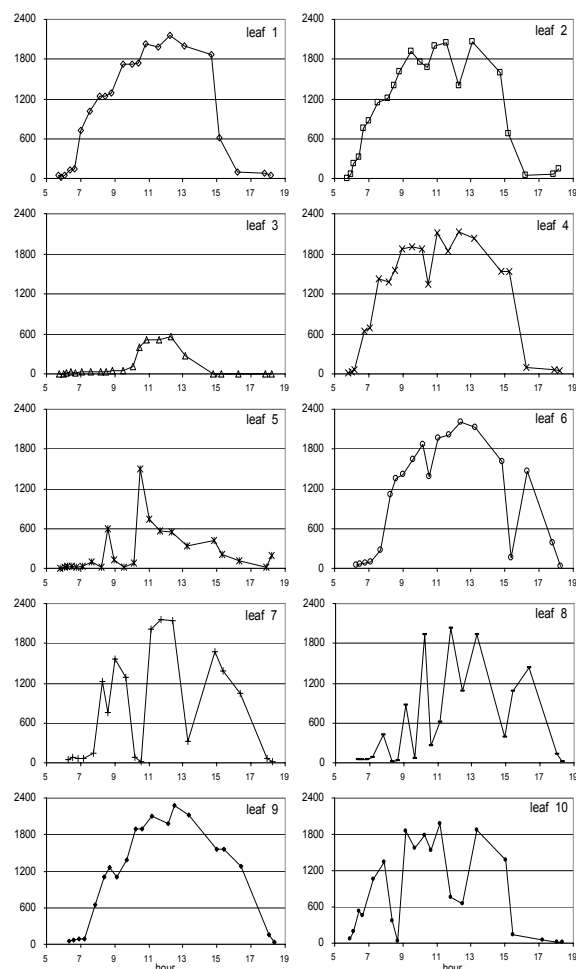
**Figure 1.** Schematic representation of the positions of ten coffee leaves used to take photosynthesis measurements during October 23, 2001.

The equipment also provided information about incident photosynthetically active radiation (PAR), leaf and air temperatures, vapor pressure deficit

(VPD) and stomatal resistance. Incident PAR was obtained at the same positions (angle) of the leaves.

## Results and discussion

Incident PAR during the day was higher on external leaves (1, 2, 4, 6, and 9), while inner leaves (3 and 5) received the lowest values (less than  $300 \mu\text{mol m}^{-2}\text{s}^{-1}$  during the most of the time); intermediate leaves (7 and 10) and leaf 8 received direct and diffuse radiation as well as some sunflecks (Figure 2).

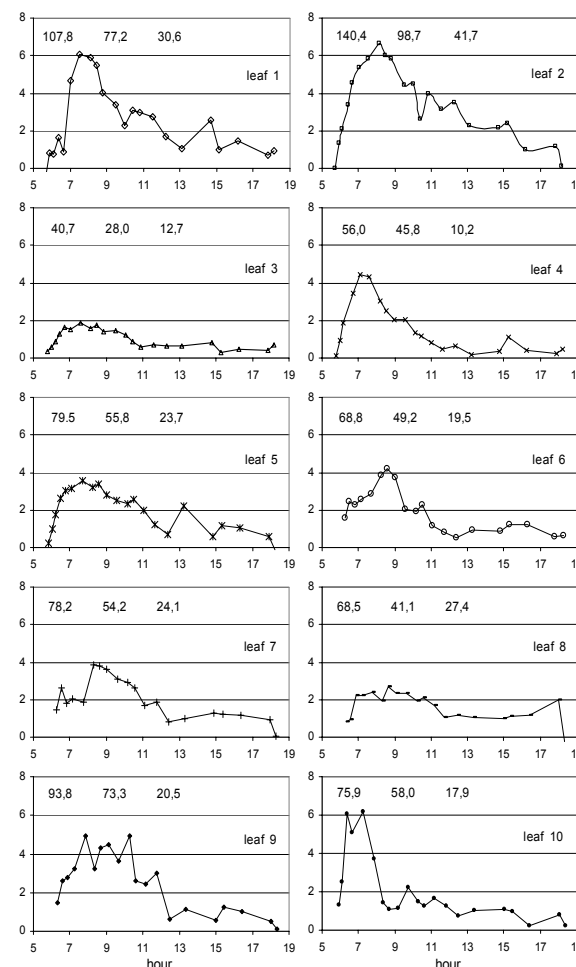


Y axis: Photosynthetically active radiation - PAR ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ ).

**Figure 2.** Photosynthetically active radiation, in  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , incident along the daytime October 23, 2001, in ten leaves at the positions shown in Figure 1.

Daily variation in photosynthetic rates showed a peak between 7:00 h and 9:00 h (Figure 3), with higher values ( $7$  to  $8 \mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ ) measured for the leaves positioned on the northern orientation (leaves 1 and 2) and at the sunrise direction (leaves 9 and 10). Lower values were consistently observed for leaves 3, 5 and 8, and sometimes for leaf 10. After 9:00 h, despite the increase in PAR (Figure 2), photosynthetic rates decreased steadily to reach negligible values at sunset. Those results are in agreement with the values measured by DaMatta *et al.*

(1997) for young coffee trees of cultivar Catuai and by Mazzafera *et al.* (1995) for high and low yield plants. Leaf 2 showed the highest values for integrated net photosynthesis, in  $\text{mmol CO}_2 \text{ m}^{-2}$ , during the whole day and during the morning (up to 12:00h); they were almost 3.5 times the values obtained by leaf 3. The integrated net photosynthesis obtained at afternoon was always less than half the values during the morning.



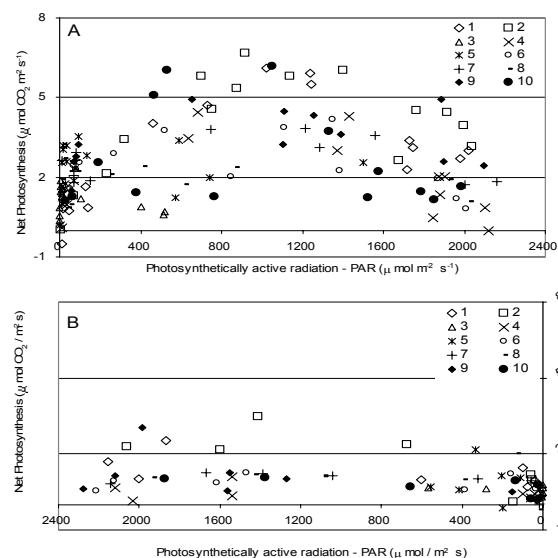
Y axis: Net photosynthesis rate ( $\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ )

**Figure 3.** Net photosynthesis rates, in  $\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1}$ , measured on October 23, 2001, in ten leaves at the positions shown in Figure 1. The three numbers inside each figure refer to the integrated net photosynthesis values during the whole day, during the morning (up to 12:00 h) and during the afternoon (from 12:00 h to the end of the day), respectively, in  $\text{mmol CO}_2 \text{ m}^{-2}$ .

The relationship between photosynthetic rates and PAR are split into two graphs in Figure 4, because photosynthesis in the afternoon was always lower than the rates in the morning for a same level of PAR. Initially there was an increase in photosynthesis with increase of PAR, a peak for PAR ranging from 600 to  $1200 \mu\text{mol m}^{-2}\text{s}^{-1}$ , and a decrease for high irradiance. Similar results were found in an experiment

conducted by Carelli *et al.* (1999), in which photosynthetic light saturation was reached at irradiance of about  $650 \mu\text{mol m}^{-2}\text{s}^{-1}$  and  $360 \mu\text{mol m}^{-2}\text{s}^{-1}$  for coffee plants cultivated under full sunlight and 50% of sunlight. The photosynthesis decreasing for high irradiance in this work may be caused by photoinhibition.

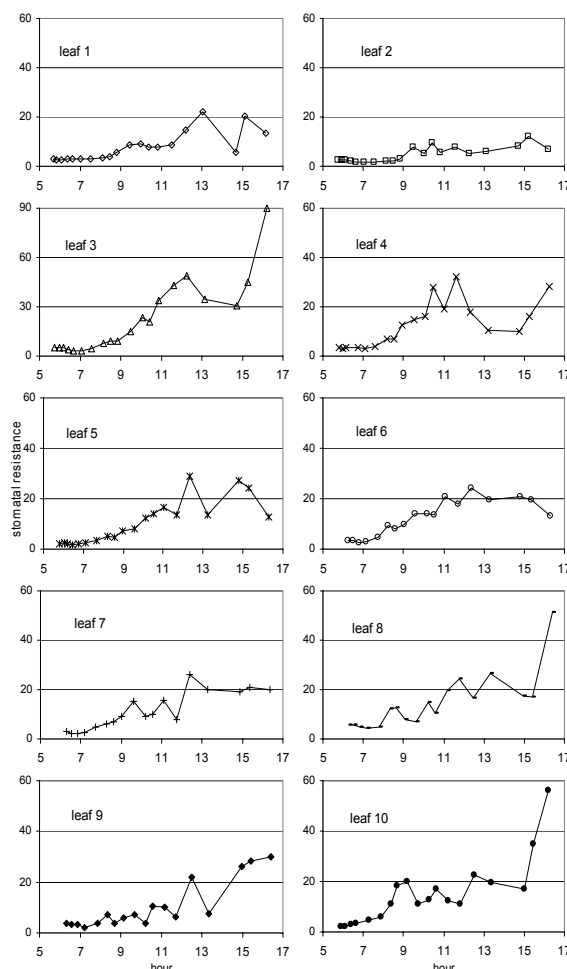
The highest and lowest photosynthesis values during the whole day, observed for leaves 2 and 3, respectively, seem to be also related to their stomatal resistances (Figure 5), mainly during the earliest hours in the morning.



**Figure 4.** Net photosynthesis rates as a function of photosynthetically active radiation, measured on ten leaves at the positions shown in Figure 1, before noon (A) and after noon (B), on October, 23, 2001.

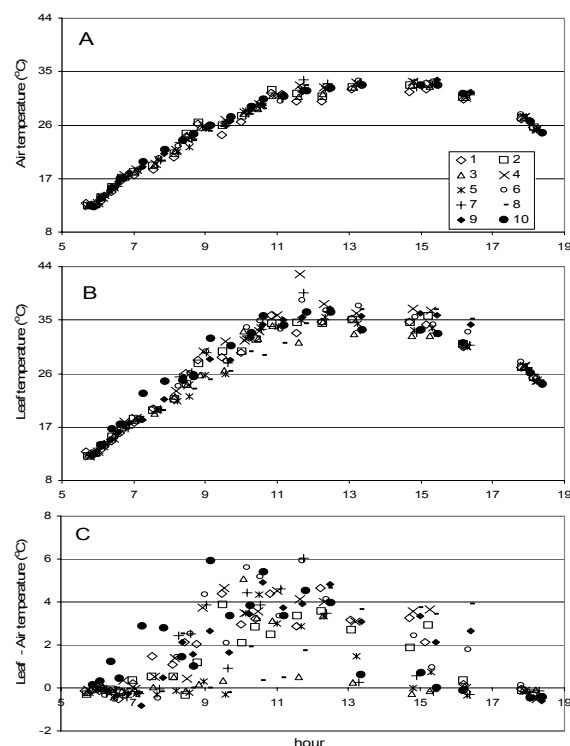
However, in spite of increased air temperatures (Figure 6-A), stomatal resistance seems not to be related to differences between leaf and air temperatures during the day (Figure 6-C), because it can be seen that leaf 3 showed the lowest values for this parameter. In our experiment, air temperatures were higher than  $25^{\circ}\text{C}$  at 9:00 h, and reaching  $32^{\circ}\text{C}$  at 12:30, which certainly led to increases in photorespiration. VPD between leaf and atmosphere obtained in each measurement showed a similar pattern as leaf temperatures during the day, while the response of photosynthetic rates to that parameter was like to the PAR (data not shown). Cannel (1976) found a progressive increase in photorespiration and internal  $\text{CO}_2$  concentration in leaves at temperatures above  $20^{\circ}\text{C}$ , resulting in stomatal closure. Kumar and Tieszen (1976) also attributed to temperature rise the cause for decreasing in photosynthesis rates at higher irradiance, because at constant leaf temperature of  $25^{\circ}\text{C}$  apparently no reduction was observed for PAR

up to  $1200 \mu\text{mol m}^{-2}\text{s}^{-1}$ .



**Figure 5.** Stomatal resistance, in  $\text{s.cm}^{-1}$ , from measurements on ten leaves at the positions shown in Figure 1, during October 23, 2001.

As a final remark, the results of the present work indicate that external leaves intercept high incident irradiance, reaching light saturation, but reflect and transmit enough quantities of photons to activate the photosynthetic machinery of shaded leaves, whose rates, however, are less than one third from that of external leaves. So, in our conditions, it is advisable to take measurements on leaves at the Northern or/and Eastern positions, when comparing photosynthesis rates in different treatments, because those present the highest values during the day. However, since number of leaves is highly variable in coffee plants, these results make evident how difficult is to integrate and estimate whole plant photosynthesis by the average of 10 leaves, like the procedure adopted here.



**Figure 6.** Air and leaf temperatures (A and B) and differences between them (C) from measurements on ten leaves at the positions shown in Figure 1, during October 23, 2001.

## Conclusion

There is a great variability on the photosynthetic rates of coffee leaves located at different positions of the plant due timely and spatially variability of PAR.

Decreases of the photosynthetic rates of coffee leaves seem to be caused by increased stomatal resistances.

## References

- CANNELL, M.G.R. Crop physiological aspects of coffee bean yield – A review. *Kenya Coffee*, Nairobi, v. 41, n. 484, p. 245-253, 1976.
- CARELLI, M.L.C. *et al.* Carbon isotope discrimination and gas exchange in *Coffea* species grown under different irradiance regimes. *Rev. Bras. Fisiol. Veg.*, Brasília, v. 11, p. 63-68, 1999.
- DaMATTA, F.M. *et al.* Photosynthesis in coffee (*Coffea arabica* and *C. canephora*) as affected by winter and summer conditions. *Plant Sci.*, London, v. 128, p. 43-50, 1997.
- FAHL, J.I., *et al.* Nitrogen and irradiance levels affecting net photosynthesis and growth of young coffee plants (*Coffea arabica* L.). *J. Hortic. Sci.*, Alexandria, v. 69, p. 161-169, 1994.
- KUMAR, D.; TIESZEN, L.L. Some aspects of photosynthesis and related processes in *Coffea arabica* L. *Kenya Coffee*, Nairobi, v. 41, n. 486, p. 309-315, 1976.
- KUMAR, D.; TIESZEN, L.L. Photosynthesis in *Coffea arabica*: effects of light and temperature. *Exp. Agric.*, London, v. 16, p. 13-19, 1980.
- MARUR, C.J. *et al.* Assimilação de CO<sub>2</sub> em diferentes espaçamentos do cafeeiro IAPAR 59. In: SIMPÓSIO DE PESQUISA DOS CAFÉS DO BRASIL, 2., 2001, Vitória. *Resumos...* Vitória: Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café. (CD-ROM).
- MAZZAFERA, P. *et al.* Investigations on coffee productivity. *J. Coffee Res.*, Karnataka, v. 5, n. 1, p. 7-18, 1995.
- MORAIS, H. *et al.* Características fisiológicas e de crescimento de cafeeiro sombreado com guandu e cultivado a pleno sol. *Pesq. Agropecu. Bras.*, Brasília, v. 38, p. 1131-1137, 2003.

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