GAS EXCHANGE IN LEAVES OF *Coffea arabica* IRRIGATED

C. C. Ronquim[1], J. F. Leivas[2], A. H. de C. Teixeira[3]

ABSTRACT - We determined maximum net photosynthesis (P_{Nmax}) in *Coffea arabica* L. (cultivars Catuaí Vermelho, Obatã, and Ouro Verde) exposed to different thermal treatments during 14 h. The optimal temperature for (P_{Nmax}) in terms of photosynthetic photon flux density (PPFD) under 355 ppm of CO_2 was between 17-23°C. Under temperatures above 23°C there was a decrease in P_{Nmax}. Under saturating CO_2 rates (1,600 ppm) the optimum temperature range changed to 23-29°C for the Catuaí Vermelho cultivar. There was no increase in P_{Nmax} under CO_2 saturation for any of the cultivars. *C. arabica*'s photosynthetic process is strongly inhibited under 32 °C leaf temperature.

KEYWORDS: CO_2, net photosynthesis, plant thermal stress.

TROCAS GASOSAS EM FOLHAS DE *Coffea arábica* IRRIGADO

RESUMO - Foi determinadas a taxa máxima de fotossíntese líquida (P_{Nmax}) em *Coffea arabica* L. (cultivares Catuaí Vermelho, Obatã e Ouro Verde) submetidos a diferentes tratamentos térmicos durante 14 h. A região ótima de temperatura para P_{Nmax} em função do fluxo de fótons fotossinteticamente ativos (PPFD) sob 355 ppm de CO_2 foi entre 17-23 °C. Sob temperaturas acima de 23 °C ocorreu o declínio de P_{Nmax}. Sob CO_2 saturante (1600 ppm) houve deslocamento da faixa de temperatura ótima para 23-29 °C no cultivar Catuaí Vermelho. Não houve incremento de P_{Nmax} sob saturação de CO_2 em nenhum cultivar. O processo fotossintético do cafeeiro é extremamente inibido sob temperatura foliar de 32 °C.

PALAVRAS-CHAVE: CO_2, estresse térmico, fotossíntese líquida.

INTRODUCTION

Photosynthetic net carbon assimilation (P_N) is one of the growth components more sensible to temperature and is likely to be the first targeted by thermal stress (Larcher, 2000).

[1] Doutor, Departamento de Geociencias, Embrapa Monitoramento por Satélite, Campinas, SP - Email: carlos.ronquim@embrapa.br
[2] Doutor, Departamento de Geociencias, Embrapa Monitoramento por Satélite, Campinas, SP - Email:
[3] Doutor, Departamento de Geociencias, Embrapa Monitoramento por Satélite, Campinas, SP - Email:

Leaf temperature affects the photosynthetic performance by means of biochemical and biophysical changes (Pastenes & Horton, 1996). Therefore, plants exposed to moderate thermal stress would not have their photosynthetic apparatus damaged, but their carbon assimilation rates would be substantially reduced.

In Brazil, *Coffea arabica* L. crops are established mainly in areas where the average annual temperature varies between 18 °C and 22 °C (Barros *et al*., 1997). The selection of cultivars has recently enabled the expansion of coffee crops to areas in which the average temperature varies between 24-25 °C with satisfactory productivity, such as the Northeast region of Brazil (DaMatta & Ramalho, 2006).

Under environmental CO_2 concentration, conditions (355 ppm) the photosynthetic carboxylation capacity in the mesophyll is not saturated (Tezara *et al*. 2002). The increase in CO_2 concentration may increase or maintain the net photosynthesis values in plants exposed to thermal stress and reduce the negative impact caused by temperature elevation to the carbon balance components.

The objective of this study was to determine the infra-optimal, optimal and supra-optimal temperatures for *C. arabica* biochemical and chemical processes. The positive and negative components of the carbon balance were related to analyze the balance of photosynthesis under irrigation and different thermal treatments. We also investigated if the increase in CO_2 concentration could reduce the impact caused by thermal stress on the carbon net assimilation.

MATERIAL AND METHODS

Plant material and growth conditions

Young four-month-old plants were grown in 20-L plastic bags containing Oxisol with animal organic matter (4:1). The soil was irrigated once a week until field capacity. The coffee seedlings were kept in a greenhouse. The average temperature in the greenhouse was 18.0±3.2°C during nighttime and 25.0±3.0°C during daytime. The soil in each bag was fertilized with 20 g of N (4.0 g), P (14.0 g), K (8.0 g), Zn (0.2 g), and B (0.1 g).

Thermal treatments within the incubator and thermal insulation of the root system

Responses for leaf net photosynthesis (P_N) in terms of photosynthetic photon flux density (PPFD) were obtained under different thermal treatments. The thermal treatments were applied using an incubator (1.25 x 0.52 x 0.17 m, model NT-708, Nova Técnica, Piracicaba, Brazil). The air temperature inside the incubator was kept steady at 17, 20, 23, 26, 29 or 32°C (± 0.1 °C). The relative humidity inside the incubator was kept constant at 70% (± 10%). The treatments were concluded after the plants were kept for 14 hours inside the incubator.

Net photosynthesis (P_N) values with regard to photosynthetic photon flux density (PPFD)

P_N-PPFD curves were obtained at 8:00 a.m. We used an infrared gas analyzer (IRGA, model LCA-4, ADC, Hoddesdon, UK) to obtain leaf gas exchange values in P_N-PPFD curves. PPFD values between 2,000-800 μmol $m^{-2}s^{-1}$ were obtained applying variable voltage to the PLU-002 cannon.

The P_N-PPFD curve was adjusted using the empirical equation described by Prado & Moraes (1997),

$$P_N = P_{Nmax} (1 - e^{-k (PPFD - Ic)}) \qquad (I)$$

where P_N = net photosynthesis; P_{Nmax} = maximum net photosynthesis; e = natural logarithm base; k = constant; PPFD = photosynthetic photon flux density; and I_c = PPFD compensation point.

Photorespiration, stomatal conductance and leaf transpiration determinations

Instantaneous determinations of stomatal conductance (g_s), transpiration (E), and of the ratio between internal and external CO_2 concentration (Ci/C_a) under PPFD values equal to or greater than 1,200 μmol.$m^{-2}s^{-1}$ in P_N-PPFD curves were used to calculate average g_s, E, and C_i/C_a values for each thermal treatment. We obtained between 33 and 42 g_s, E, and C_i/C_a values for each P_N-PPFD curve under saturating PPFD.

Net photosynthesis (P_N) with regard to external (C_a) and intercellular (C_i) CO_2 concentration

P_N-C_a and P_N-C_i curves were obtained under PPFD saturation (1.200 μmol.$m^{-2}s^{-1}$) using a GD gas diluter (ADC, Hoddesdon, UK) coupled to the LCA-4 IRGA (Monteiro & Prado 2006). We modified equation (I) replacing the PPFD component by CO_2 concentration and used the modified equation to adjust the P_N-C_a and P_N-C_i curves, thus obtaining the potential photosynthetic capacity, $P_{Nmax\,(CO2)}$ (μmol.$m^{-2}s^{-1}$).

RESULTS

The highest P_{Nmax} values under regular atmospheric concentration were observed at 17°C for the Ouro Verde (8.3 μmol $m^{-2}s^{-1}$) cultivar and under 20°C for the Obatã and Catuaí Vermelho cultivars, at 7.8 and 7.1 μmol $m^{-2}s^{-1}$ respectively (Table 1 and Figure 1). P_{Nmax}

decrease occurred beyond 20°C for all cultivars, and under 32°C the carbon assimilation was less than 1.4 μmol $m^{-2}s^{-1}$.

Stomatal conductance (g_s) and transpiration (E) under saturating PPFD decreased with leaf temperature elevation (Figure 2). The temperature elevation did not restrain the internal/external carbon concentration relationship values (C_i/C_a, Figure 2).

Under irradiance (PPFD) and CO_2 saturation conditions there was also a decrease in P_{Nmax} with temperature elevation (Figure 3 and Table 1). The optimum temperature for carbon assimilation in the Catuaí Vermelho cultivar increased to 26°C under saturating CO_2 concentration. *C. arabica* showed no increase in P_{Nmax} values in the P_N-CO_2 curves, since the maximum value obtained (8.5 μmol $m^{-2}s^{-1}$, Catuaí Vermelho under 26 °C) is close to the maximum value registered under regular atmospheric concentration (8.3 μmol $m^{-2}s^{-1}$, Ouro Verde under 17°C). Even under 1.600 ppm of CO_2, *C. arabica* photosynthesis is strongly inhibited at 32°C (Figure 3), especially in the Catuaí Vermelho and Obatã cultivars (1.6 and 1.4 μmol m^{-2} s^{-1} respectively).

DISCUSSION

Contrasting with the scenario under less elevated temperatures, P_{Nmax} inhibited under 32°C (Table 1 and Figure 1). This behavior showed by *C. arabica* confirms our expectation that besides producing a decrease in CO_2 photosynthetic fixation (He & Lee, 2001). Additionally, the significant reduction in P_{Nmax} and $P_{Nmax(CO2)}$ observed for the coffee plant under 32°C confirms the RuBisCO activation state is intensely affected by elevated temperatures.

The absence of a displacement in P_{Nmax} optimum temperature for the Obatã and Ouro Verde cultivars indicates possible mesophyll limitation to net photosynthesis. On the other hand, photosynthetic models assume that a constant C_i/C_a ratio under temperature (Figure 2) and CO_2 atmospheric concentration elevation indicates a parallel adjustment of the stomatal apparatus and of the photosynthetic activity in the mesophyll (Morison & Lawlor, 1999). Reduced CO_2 mesophyll conductance due to abiotic stress may produce large differences between C_i and effective carbon concentration in the chloroplast (Bota *et al.*, 2004).

The displacement in optimum temperature for net assimilation only for the Catuaí Vermelho cultivar cannot be explained exclusively based on the results obtained here. Interspecific differences in answers to temperature and CO_2 concentration interactions are expected among genotypes and cultivars due to the different development forms and expansion of meristems and organs, and to the assimilates' allocation pattern in these organs (Morison & Lawlor, 1999).

Carboxylation efficiency is generally correlated to RuBisCO activity (von Caemmerer, 2000). It's activity decreases when g_s becomes lower than 0.10 mol $m^{-2}s^{-1}$ (Tezara *et al*. 2002, Bota *et al.* 2004). The results obtained here show the stomatal conductance was always below this value at temperatures above 17°C (Figure 2). Stomatal diffusion limitation would already be reaching its potential at cool temperatures, therefore it suffered less variation under thermal stress.

Elevated CO_2 concentrations do not enhance coffee's net photosynthesis (Figure 3). In this sense, some other previous reports are also divergent. *Triticum aestivum* showed only 10% increase in P_{Nmax} under doubled regular C_a, and an increase of only 4 °C in environmental temperature decreased its photosynthetic capacity and carboxylation efficiency (Delgado *et al*. 1994).

CONCLUSIONS

C. arabica cultivars show greater carbon fixation between 17-23°C. Coffee plants show no increase in carbon gain under saturating CO_2 conditions, but the Catuaí Vermelho cultivar shows optimum temperature range displacement for higher temperature values (23-29°C). Coffee plants' photosynthetic process is strongly inhibited under a 32°C leaf temperature, both under regular atmospheric conditions and under saturating CO_2 conditions.

REFERENCES

BARROS, R.S.; MOTA, J.W.; DAMATTA, F.; MAESTRY, M. Decline of vegetative growth in *Coffea arabica* L. in relation to leaf temperature, water potential and stomatal conductance. Field Crop Research 54. p. 65-72, 1997.

BOTA, J.; MEDRANO, H.; FLEXAS, J. Is photosynthesis limited by decreased Rubisco activity and RuBP content under progressive water stress? New Phytologist 162. p. 671-681, 2004.

DAMATTA, F.; RAMALHO, J.D.C. Impacts of drought and temperature stress on coffee physiology and production: a review. Brazilian Journal of Plant Physiology 18. p. 55-81, 2006.

DELGADO, E.; MITCHELL, R.A.C.; PARRY, M.A.J.; DRISCOLL S. P.; MITCHELL V. J.; LAWLOR D. W. Interacting effects of CO_2 concentration, temperature and nitrogen supply on the photosynthesis and composition of winter wheat leaves. Plant, Cell and Environment 17. p. 1205-1213, 1994.

HE, J.; LEE, S. Relationship among photosynthesis, ribulose-1,5-biphosphate carboxylase (Rubisco) and water relations of the subtropical vegetable Chinese broccoli grown in the tropics by manipulation of root-zone temperature. Environmental Experimental Botanic 46. p. 119-128, 2001.

LARCHER, W. Ecofisiologia Vegetal. Editora RiMa, São Carlos. 2000.

MONTEIRO, J.A.F.; PRADO, C.H.B.A. Apparent carboxylation efficiency and relative stomatal and mesophyll limitations of photosynthesis in an evergreen cerrado species during water stress. Photosynthetica 44. p. 39-45, 2006.

MORISON, J.I.L.; LAWLOR, D.W. Interactions between increasing CO_2 concentration and temperature on plant growth. Plant, Cell and Environment 22. p. 659-682, 1999.

PASTENES, C.; HORTON, P. Effect of high temperature on photosynthesis in beans. Plant Phisiology 112. p. 1253-1260, 1996.

PRADO, C.H.B.A.; MORAES, J.A.P.V. Photosynthetic capacity and specific leaf mass in twenty woody species of cerrado vegetation under field conditions. Photosynthetica 33. p. 103-112, 1997.

TEZARA, W.; MITCHELL, V.; DRISCOLI, S.P.; LAWLOR, D.W. Effects of water deficit and its interaction with CO_2 supply on the biochemistry and physiology of photosynthesis in sunflower. Journal of Experimental Botany 53. p. 1781-1791, 2002.

Table 1. Potential photosynthetic capacity with regard to internal CO_2 concentration (P_{Nmax} (CO_2), µmol $m^{-2}s^{-1}$) in *Coffea arabica* Catuaí Vermelho, Ouro Verde and Obatã cultivars kept under thermal treatment for 14 hours at 17, 20, 23, 26, 29 and 32°C.

	cv.	17 °C	20 °C	23 °C	26 °C	29 °C	32 °C
	Catuaí	6.8	7.6	7.2	8.4	3.8	1.6
$P_{Nmax\ (CO2)}$	Obatã	4.8	5.6	5.3	4.4	3.3	1.4
	Ouro Verde	7.3	6.1	6.3	4.9	3.8	3.0

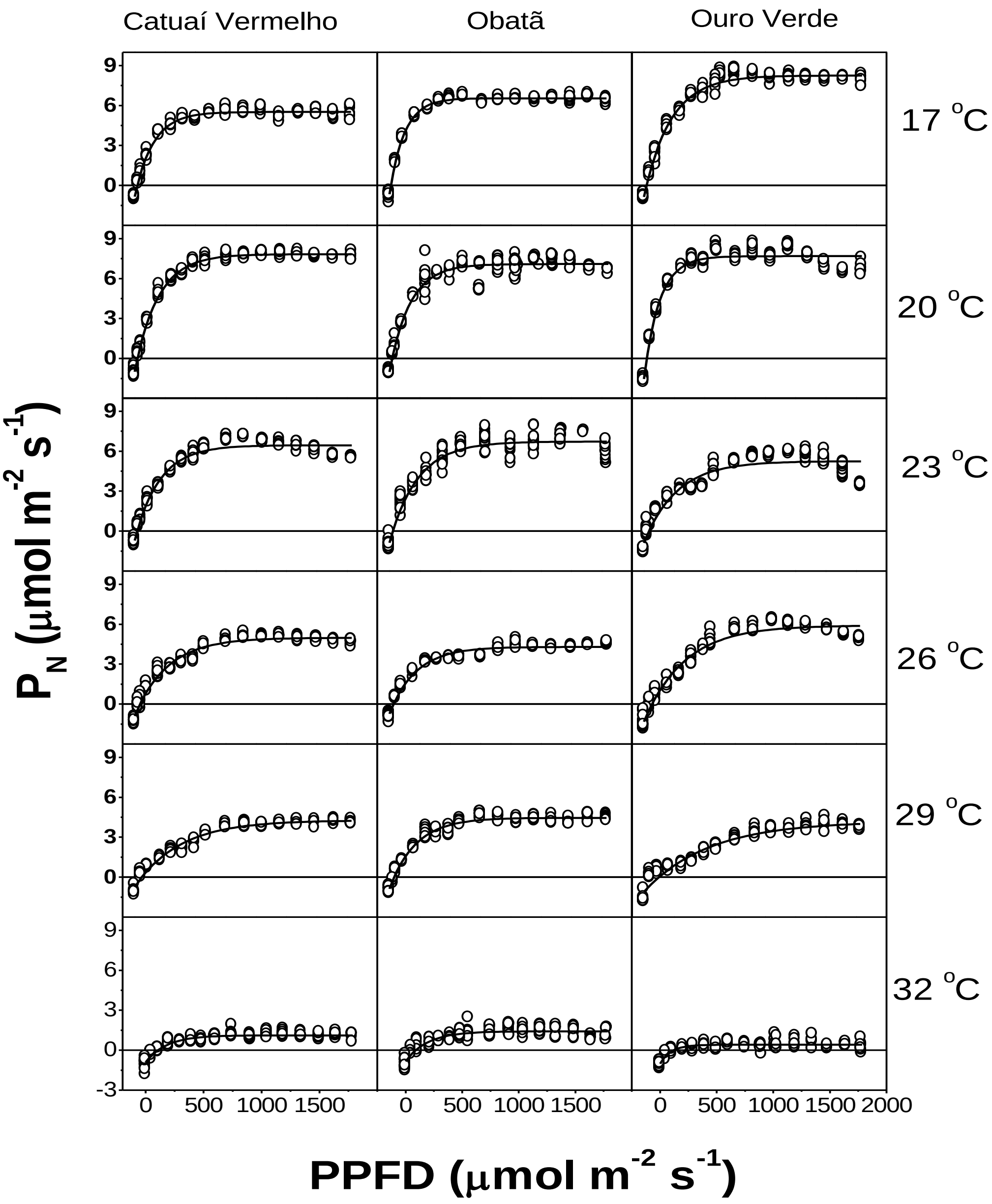

Figure 1. Net photosynthesis (P_N, open circles) with regard to photosynthetically active photon flux (PPFD) under regular CO_2 atmospheric concentration (355 ppm) in *Coffea arabica* cultivars Catuaí Vermelho, Obatã and Ouro Verde after 14 hours in an incubator under 17 °C (upper panels), 20 °C, 23 °C, 26 °C, 29 °C and 32 °C (lower panels).

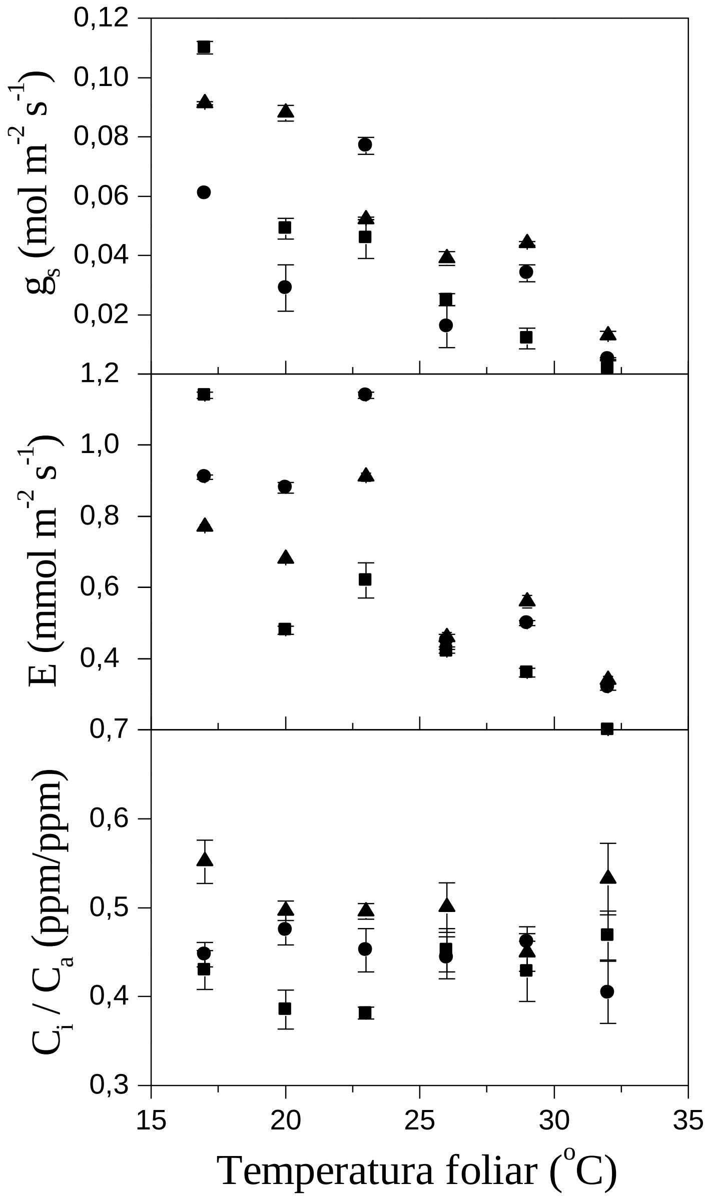

Figure 2. Stomatal conductance (g_s), transpiration (E) and internal/external concentration ratio (C_i/C_a) under photosynthetically active photon flux (PPFD) ≥ 1.200 μmol m^{-2} s^{-1} after 14 hours under different temperatures in *Coffea arabica* cultivars: Catuaí (■), Obatã (●) and Ouro Verde (▲). Each symbol represents the average value (42 ≥ n ≥ 33) and the bars represent standard error.

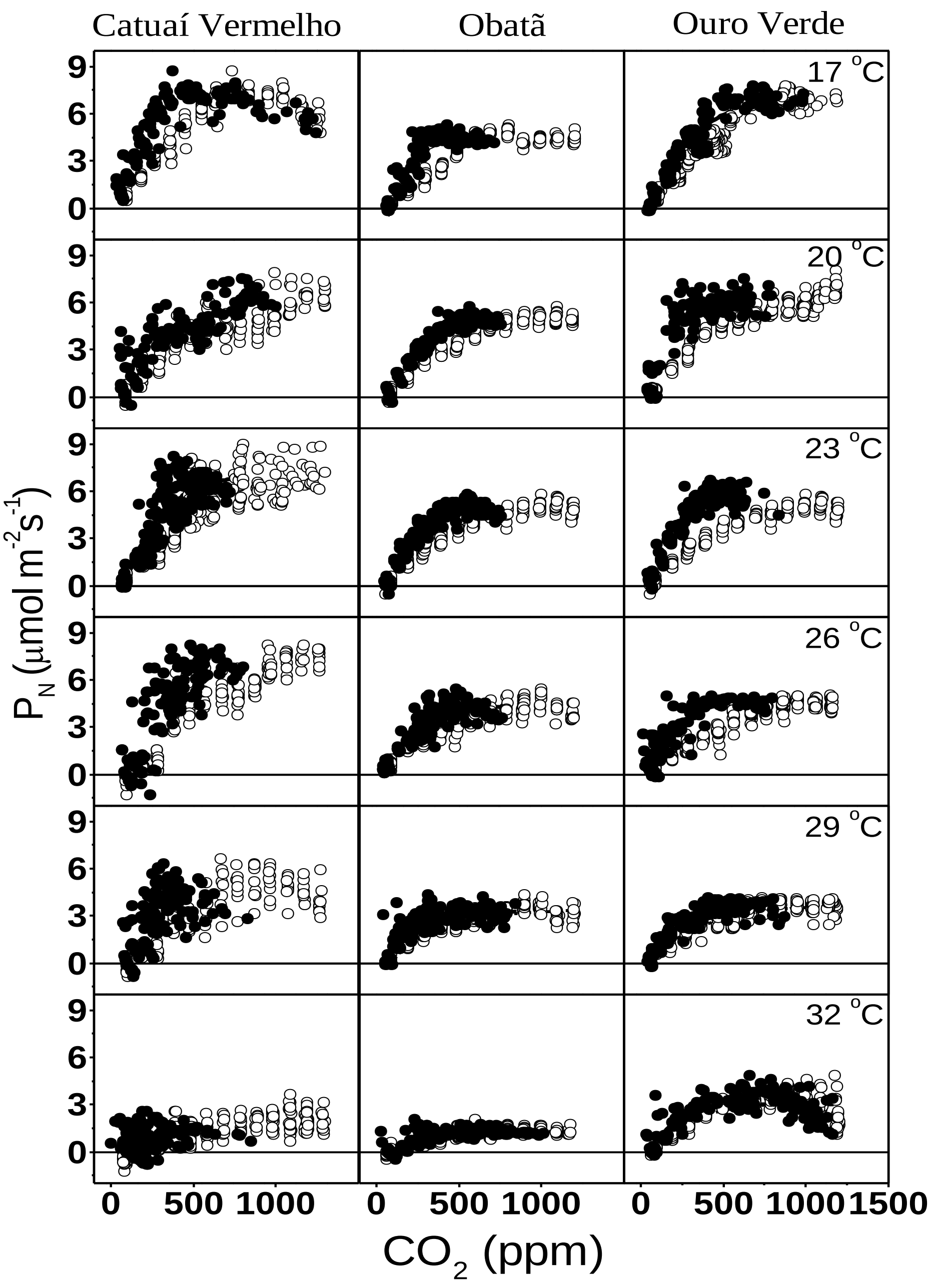

Figure 3. Net photosynthesis (P_N) under saturating (1.200 μmol $m^{-2}s^{-1}$) photosynthetically active photon flux (PPFD) with regard to external (C_a, open circles) and intercellular (C_i, solid circles) CO_2 concentrations in *Coffea arabica* Catuaí Vermelho, Obatã and Ouro Verde cultivars after 14 hours in an incubator under 17, 20, 23, 26, 29 and 32 °C.