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Gas exchange in gariroba palms grown under subtropical conditions

Valéria A Modolo[1]; Norma M Erismann[2]; Maria Luiza S Tucci[2]

[1]Instituto Agronômico, Centro de Horticultura (IAC), Campinas-SP, Brazil; vamodolo@iac.sp.gov.br; [2]Instituto Agronômico, Centro de Ecofisiologia e Biofísica (IAC), Campinas-SP, Brazil; normaeri@iac.sp.gov.br; tucci@iac.sp.gov.br

ABSTRACT

Gariroba palm, native to Brazil, produces bitter heart-of-palm, consumed as vegetable in salads, as well as in other Brazilian recipes. This research was carried out in field condition to evaluate diurnal and seasonal variation of gas exchange of gariroba palms cultivated under subtropical conditions, considering their interrelation with some climate elements. Plants were evaluated within two consecutive years, grown under field conditions and irrigated, spaced 2x1 m. Net assimilation of CO_2 (P_N), stomatal conductance (g_s), transpiration (E), leaf temperature (T_l) within the chamber and the photosynthetic photon flux density (PPFD) were evaluated. Water use efficiency (WUE) was estimated by the ratio: WUE = P_N/E. Net CO_2 assimilation (P_N), showed a plateau in May, observed from 9:30 to 14 h, reaching an average of 5.4 μmol $m^{-2}s^{-1}$, then declining toward late afternoon. As far as August is concerned, P_N increased from the early morning until 11 h, reaching the maximum value of 9.0 μmol $m^{-2}s^{-1}$. From then on it decreased reaching 6.0 μmol $m^{-2}s^{-1}$ at 14 h. Gariroba palms cultivated and even under lower autumn and winter temperatures presented gas exchange characteristics consistent to climatic elements.

Keywords: *Syagrus oleracea*, photosynthesis, bitter heart-of-palm.

RESUMO

Trocas gasosas em palmeira gariroba cultivada sob condições subtropicais

Nativa do Brasil, a garirobeira produz palmito amargo, consumido como hortaliça em saladas, bem como em outras receitas da culinária brasileira. Este trabalho foi realizado em condição de campo para avaliar as variações diurnas das trocas gasosas de garirobeiras, considerando sua inter-relação com alguns elementos climáticos. Foram realizadas avaliações em garirobeiras cultivadas no espaçamento 2x1 m, conduzidas sob irrigação, durante dois anos consecutivos. Foram avaliadas a assimilação líquida de CO_2 (P_N), condutância estomática (g_s), transpiração (E), temperatura foliar (T_f) dentro da câmara e densidade de fluxo de fótons fotossinteticamente ativos (DFFF). A eficiência do uso da água (EUA) foi estimada pela razão: EUA = P_N/E. A assimilação líquida de CO_2 (P_N), mostrou um platô em maio, observado entre 9 e 14 h, atingindo média de 5,4 μmol $m^{-2}s^{-1}$, em seguida declinando no fim da tarde. Em agosto, P_N aumentou a partir do início da manhã até as 11h, quando atingiu o máximo de 9,0 μmol $m^{-2}s^{-1}$. A partir de então, decresceu, atingindo 6,0 μmol $m^{-2}s^{-1}$ às 14 h. Mesmo sob temperaturas mais baixas de outono e inverno as garirobeiras cultivadas apresentaram trocas gasosas compatíveis com os elementos do clima.

Palavras-chave: *Syagrus oleracea*, fotossíntese, palmito amargo.

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Heart-of-palm, a product from the upper part of the stem of some palms was already consumed by several native people in Brazil as well as other countries of South and Central America, since ancient times. The abundance of this vegetal material as well as its acceptation by consumers made heart-of-palm to be considered a gourmet vegetable, allowing establishment of rentable market based on exploitation of this product (Modolo *et al*., 2013).

Many palm species of the Brazilian flora are appreciated and the most important market is represented by those of sweet type such as juçara palm (*Euterpe edulis*), açaí (*Euterpe oleracea*) and peach palm (*Bactris gasipaes*) (Modolo *et al*., 2012).

Gariroba palm (*Syagrus oleracea*), also known as guariroba, gueroba, gueiroba, guerova, differs from other heart-of-palm producing palms by the characteristic flavor of its heart-of-palm, presenting high content of phenols that gives a bitter and astringent taste, highly appreciated in the culinary of many regions. This characteristic results probably from the high tannin content (almost three times higher than the juçara palm) as well as some amino acids such as phenylalanine, tyrosine and proline (Shimokomaki *et al*., 1975). Besides the bitter taste, heart-of-palm presents a harder consistency once its major part is of caulinar type. The edible portion weighs from 0.5 to 3.0 kg in average.

Gariroba palm is native to semi-deciduous forests as well as to the Brazilian "cerrado" occurring naturally in a wide range, including Bahia, Minas Gerais, São Paulo, Mato Grosso, Mato Grosso do Sul, Goiás and Tocantins (Lorenzi *et al*., 2010). Due to its geographic origin, this species is acclimated to high sun radiation and low rain precipitation from 800 to 1200 mm/year, withstanding soil water deficits throughout the winter months. Nevertheless, for commercial gariroba palm production, planting density is high, that is 10.000 to 22.000 plants ha^{-1} (Modolo, 2014) and thus restriction factors to plant growth (fertilization and water deficit) should be observed. The lack of a cultivar makes plant growth and consequently harvesting uneven, even under proper cultivation conditions (plants are maintained on the same area for 3 to 4 years). The knowledge of gariroba palm gas exchange under subtropical conditions will contribute to comprehension of its photosynthetic pattern under irrigation.

Palms show maximum values of CO_2 assimilation (P_N) under 20 µmol $m^{-2}s^{-1}$ (Jayasekara & Jayasekara, 1995). On the other hand, Larcher (2000), suggested for C3 trees, maximum P_N between 10 and 15 µmol $m^{-2}s^{-1}$. Differently to what has been observed for palms of more economical importance like coconut (Gomes & Prado, 2007; Gomes *et al*., 2008; Passos *et al*., 2009), oil palm (Dufrêne & Saugier, 1993; Suresh *et al*., 2012) and lately the heart-of-palm producer palms (Tucci *et al*., 2007, 2010; Lavinsky *et al*., 2014; Pereira *et al*., 2014), no references to gariroba palms gas exchange were found.

Nevertheless, regarding other species of genus *Syagrus*, a study was carried out on the species *S. coronata*, under greenhouse conditions and water deficit imposed by water withdraw, and a tolerance of photosynthetic apparatus to drought was observed (Medeiros *et al*., 2015). In dry season of the Brazilian northeast semi-arid, *S. coronata*, presented low sensibility to low water availability and high water use efficiency (Oliveira *et al*., 2016). Regarding anatomic characteristics of leaves, the species of genus *Syagrus* present a thick cuticle that can be considered a protection against desiccation, once these species thrive in regions prone to soil water deficits (Leite & Scatena, 2001; Oliveira *et al*., 2016).

It is known that gas exchange variation both diurnal and seasonal are influenced by climate elements characteristic of the region, mainly light, air temperature and air relative humidity, besides soil water availability (Koslowski & Pallardi, 1997).

This research was carried out to evaluate diurnal and seasonal variation of gas exchange of gariroba palms cultivated under subtropical conditions, considering their interrelation with some climate elements.

MATERIAL AND METHODS

The experiment was carried out at Campinas Experimental Center, Instituto Agronômico (IAC), in Campinas, São Paulo State, Brazil (22º54'S; 47º05'O, 674 m altitude). According to Köppen classification, the climate is Cwa with a warm and rainy season from October to March, medium air temperature from 22 to 24ºC and 1057 mm precipitation; a dry season from April to September, with medium air temperature varying from 18 to 22ºC, 325 mm precipitation, according to Ortolani *et al*. (1995).

Young gariroba palm plants raised from seeds of open pollinated matrices were transplanted to field conditions, spaced 2x1 m. Soil analysis at the beginning of the experiment presented the following chemical characteristics: pH ($CaCl_2$)= 6.0; organic matter (g dm^{-3})= 29.0; C.T.C. (mmolc dm^{-3})= 100.4; V%= 78%; P (mg dm^{-3})= 40.0; K (mmolc dm^{-3})= 2.9; Ca (mmolc dm^{-3}) = 53.0; Mg (mmolc dm^{-3})= 22.0; Fe (mg dm^{-3})= 14.0; Mn (mg dm^{-3})= 5.9; Cu (mg dm^{-3})= 4.1; Zn (mg dm^{-3})= 1.2; B (mg dm^{-3})= 0.25; H+Al (mmolc dm^{-3})= 22.0; S.B. (mmolc dm^{-3})= 77.9. Two months before transplantation the area was plowed and, according to soil analysis and recommendation (Bovi & Bortoletto, 1998), 500 kg ha^{-1} of dolomitic limestone were incorporated. After, grooves were opened for the young plants transplantation. No chemical fertilization was applied at planting. According to soil analysis 120 g of N, 12 g of K_2O and 6 g of P_2O_5 were applied per plant, four doses per year, starting seven month after planting. Plants were irrigated through microaspersion, one emissor for each 2 plants and defined according to culture evapotranspiration (ET_C), estimated using the reference evapotranspiration (ETo) by Penman-Monteith method (Allen *et al*., 1998), calculated based on meteorological data of the local climate station. According to Delgado-Rojas *et al*. (2012), the transpiration of an irrigated area of peach palm represents 92% of the ETo on average; therefore considering decrease of the irrigation efficiency due to direct evapotranspiration, the crop coefficient (Kc) for peach palm is considered to be 1, that is ETc = ETo. On the other hand, despite the fact that gariroba palm does not emit off-shoots like peach palm, it has same growth characteristic and approximately same foliar area. Therefore the use of same parameter of ETc estimative was chosen to irrigate the experimental area. In the first year, six month-old gariroba palms still presenting biphid leaves were evaluated. Gas exchange evaluations were carried out under field conditions, in May 2012. In August 2013, gariroba palms of the same area now 21 month-old, presenting pinnate leaves, were evaluated.

Experiment was arranged in a completely random design and data were subjected to analyses of variance considering both evaluation months (May and August) and time of day (five times) as source of variation. Net CO_2 assimilation (P_N), stomatal conductance (g_s), transpiration (E), leaf temperature (T_l) inside chamber and photosynthetic photon flux density (PPFD) were evaluated. Evaluations were performed with a portable infrared gas analyzer (LCA-4, ADC BioScientific Ltd., Great Amwell, U.K.). Water use efficiency (WUE) was estimated by the ratio WUE = P_N/E. Measurements were performed on the medium portion of the youngest completely expanded leaf (leaf +1), according to Tomlinson criteria (Tomlinson, 1990) and throughout the experiment, leaves of the same ontogenetic state were evaluated, for both dry and wet seasons in sunny days from 8 to 17 h. Air temperatures and relative humidity (RH) were monitored by a meteorological station at 300 m from the experimental area. Average diurnal data were calculated from 3 to 6 replications. When significance was observed mean values were submitted to Student-Newman-Keuls multiple range test ($p \leq 0.05$). Graphs were performed according to Origin 6.0 (OriginLab Corp., Northampton, USA) program.

RESULTS AND DISCUSSION

Under subtropical conditions it is important to consider that once plants had been irrigated, other climate

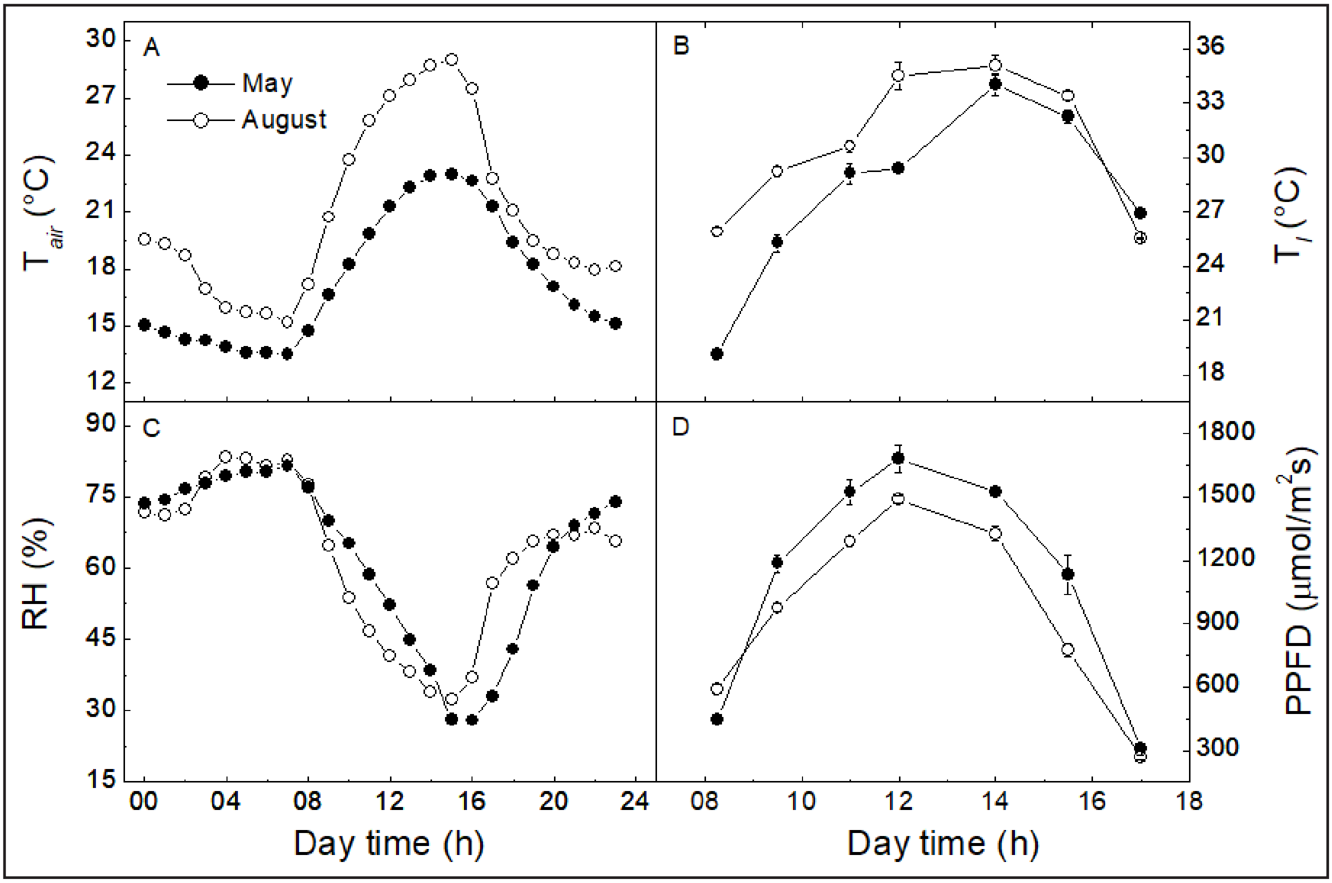

Figure 1. Diurnal courses of average air temperature (T_{air}) and relative air humidity (RH) (A, C), provided by a meteorological station, and leaf temperature (T_l) and photosynthetic photon flux density (PPFD) (B, D), registered inside the gas analyzer chamber on May, 2012 (●) and on August, 2013 (○). Note that the scales on the x-axes of the right frames are different from those on the left. Campinas, IAC, 2012/2013.

elements other than the soil water status can have imposed some effect on gas exchange.

Concerning air temperature in May, minimum (14ºC) and maximum (23ºC) values were observed at 7 and at 15 h, respectively. Whereas RH was minimum from 15 to 16 h, reaching 28%, leaf temperature varied from 19 to 34ºC, at 8 and 14 h respectively (Figure 1A and 1B). In August 2013 air temperatures were higher, with minimum (15°C) and maximum (29ºC) values observed at 7 and 15 h, respectively with leaf temperature varying from 26 to 35ºC, from 8:30 to 13:30 h, respectively, whereas RH was minimum at 15 h reaching 32% (Figure 1C and 1D). Measurements in May 2012 were performed under autumn conditions, with milder air temperatures than the occurring on following year (August 2013), end of winter, with plants prepared to another growth cycle.

Regarding gas exchange, variance analyses of both evaluations showed significant difference ($p \leq 0.05$) among days and hours for the following variables P_N, g_s, E, T_l and PPFD. On the other hand for WUE, differences were observed ($p \leq 0.05$) only among hours.

P_N, g_s, E, T_l were higher at second year. Average values of P_N, including all measurement times were 4.0 and 6.5 µmol $m^{-2} s^{-1}$ for the first and second years, respectively. Concerning g_s, medium values were 0.172 mol $m^{-2} s^{-1}$ at first year and higher at second year reaching 0.238 mol $m^{-2} s^{-1}$. E corresponded to 1.59 and 2.66 mmol $m^{-2} s^{-1}$ at first and second years, respectively, whereas average value of T_l presented the same tendency, lower at first year (27.6ºC) and higher at second (30.6ºC). Like it was observed for peach palm (Tucci *et al*., 2010), although other climate elements were favorable, P_N was lower because of the lower temperature at the night previous to measurements.

It is known that climate elements mainly PPFD, temperature and air RH influence directly gas exchange of all plant species and its impact is of high importance to physiology of production, once productivity depends highly on the P_N throughout the crop cycle (Taiz & Zeiger, 2009).

Like all palms (Tucci *et al*., 2010; Prado *et al*. 2001; Passos *et al*., 2009), gariroba palm presented diurnal variation of gas exchange with a performance consistent with that of photosynthetic metabolism of C3 plants (Larcher, 2000), both in May and in August (Figure 2 and 3).

Daily courses of P_N, g_s, E, WUE, showed variations according to climate conditions observed throughout evaluations in May (Figure 2) and August (Figure 2). In May, 2012, P_N increased in early morning (Figure 2A) following the increase of PPFD (Figure 1B), remaining constant until 14 h. The maximum medium value of P_N observed at the plateau from 9 to 14

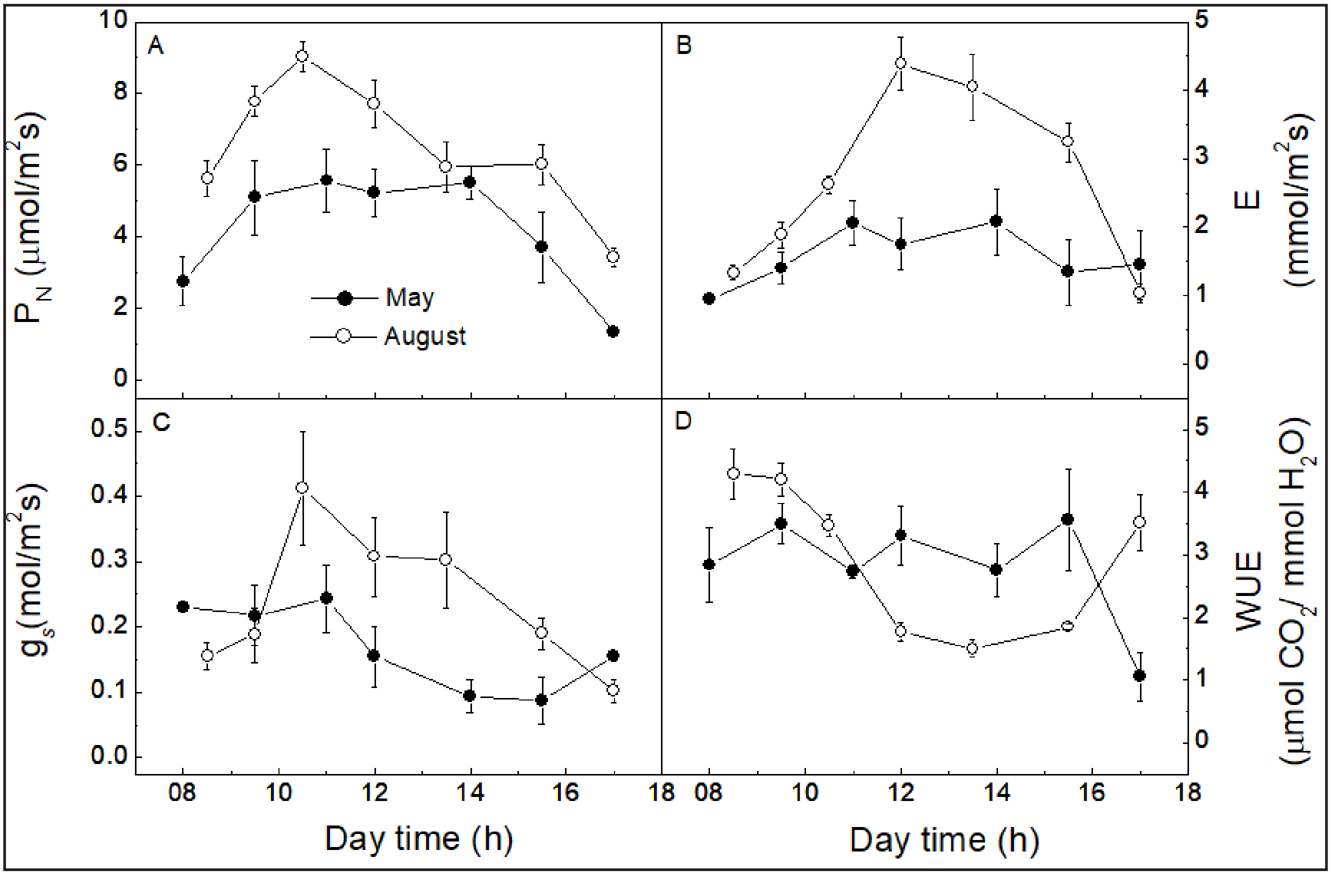

Figure 2. Diurnal courses of net CO_2 assimilation - P_N (A), transpiration - E (B), stomatal conductance - g_s (C) and water use efficiency - WUE (D), in gariroba palms, on May, 2012 (●) and on August, 2013 (○). Each symbol represents the mean value (± standard error) of three to six replications. Campinas, IAC, 2013.

h was 5.4 μmol m^{-2} s^{-1}. A depression was not noted neither on the P_N curve nor on the E curve at 14 h, although g value was lower.

Values of g remained around 0.23 mol m^{-2} s^{-1} from 8 to 11 h, declining with decrease of RH in afternoon, although E remained constant, around 2.0 mmol $m^{-2}s^{-1}$ until 14 h. From 14 to 16 h P_N decreased probably due to decrease of g and to the low RH that reached 28%, despite the fact that PPFD was over 1000 μmol m^{-2} s^{-1}, what for a C3 plant like gariroba palm is over the photosynthesis saturation by PPFD (Larcher 2000). WUE (Figure 2D) remained high from early morning to 16 h. P_N decrease at 16 h followed the low PPFD of late afternoon (Figure 1B).

Regarding the daily courses observed in August (Figure 2), P_N increased from early morning to 11 h, when it reached the maximum value of 9.0 μmol $m^{-2}s^{-1}$. From then on P_N decreased 33% until 14 h ($p \leq 0.05$), reaching 6.0 μmol $m^{-2}s^{-1}$ at 14 h still under PPFD over 1200 μmol $m^{-2}s^{-1}$. From 14 to 16 h P_N values remained constant, dropping with PPFD decrease (Figure 1D).

Diurnal variation of g_s followed the same P_N pattern, presenting maximum value of 0.412 mol $m^{-2}s^{-1}$, under maximum P_N (Figure 2C). On the other hand, E was maximum reaching 4.4 mmol $m^{-2}s^{-1}$ around noon, when T_l reached the maximum value of 35ºC. From this point on, g and P_N decreased (Figure 1 and 3). After 12 h, higher values of air temperature and T_l were observed, concomitantly to lower values of RH (Figure 1C), what may have contributed for the decrease of WUE from 12 to 16 h, when it reached values under 2.0 μmol CO_2 /mmol $H_2$0. From then on it recovered the status of the early morning, over 3 μmol CO_2/mmol $H_2$0 (Figure 2D).

It is important to remember that gariroba palms were under irrigation throughout the experiment and therefore variations of g_s and P_N have not been due to soil water deficit, but to atmospheric conditions of the evaluation days.

Results can be considered consistent with the environmental conditions observed when measurements were performed. Maximum P_N value of 9.0 μmol $m^{-2}s^{-1}$ in August can be compared to that of 10 μmol m^{-2} s^{-1} observed for *S. coronata* under field conditions of the Pernanbuco State semi-arid region in the rainy season (Oliveira *et al*., 2016). In irrigated peach palms under subtropical conditions of São Paulo State, Brazil, P_N maximum reached 15 μmol $m^{-2}s^{-1}$ in February (Tucci *et al*., 2010). In other palms of economic importance, like dwarf coconut, P_N reached values of 14-17 μmol $m^{-2}s^{-1}$ (Gomes & Prado, 2007; Gomes *et al*. 2008; Passos *et al*. 2009).

Therefore, it can be considered that maximum values of P_N of 5.4 and 9.0 μmol $m^{-2}s^{-1}$ observed for gariroba palms in May and August respectively, could not represent the maximum limit for P_N of the species. In other seasons, under favorable conditions, such as hot and humid summers, gariroba palm may present maximum values of P_N higher than the mentioned in present study. Therefore it is important to consider that gas exchange measurements were performed in May and August when air temperatures at night and pre-dawn reached minimum values of 14-15ºC (Figure 1A and 1C). This fact could have contributed to the decline of gariroba palm P_N mainly in May, when air temperature remained under 15ºC during 7 hours (Figure 1A).

It is worth observing that evaluations were performed in May and August, autumn and winter, respectively. As a matter of fact, according to what has been related for peach palm (Tucci *et al*., 2010), low night temperatures lowered the photosynthetic response. The same effect was observed in other species like mango (Allen *et al*., 2000) and citrus (Ribeiro *et al*., 2009 a,b), what was considered by Allen *et al*. (2000), as a consequence of a stomatal limitation of P_N due to an increase of sensitivity of guard cells to intercellular CO_2.

In August, but not in May (Figure 2), variation of diurnal course of gas exchange followed the model described by Koslowski & Pallardi (1997) for tropical plants, that is, P_N increased sharply at the beginning of morning, paralleling PPFD, reaching the maximum value at mid morning. On the other hand, in May probably due to night (and diurnal) temperatures lower than in August (Figure 1A and 1C), stomata were maintained more closed throughout the day course, with lower values of P_N throughout the day, without showing the characteristic peak in morning.

Results showed that under subtropical conditions, gariroba palms cultivated under irrigation, even under the lower temperatures of autumn and winter, showed gas exchange consistent with the climate elements. Nevertheless, considering the climate seasonality and its direct effects on heart-of-palms production, other studies under other season conditions would be performed.

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