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Gas exchange in 'BRS Princesa' banana (*Musa* spp.) under partial rootzone drying irrigation in the north of Minas Gerais, Brazil

Intercambio de gases en banano (*Musa* spp.) 'BRS Princesa' bajo riego lateralmente alternado en norte de Minas Gerais, Brasil

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Abstract

This research aimed to evaluate physiological characteristics of 'BRS Princesa' banana under partial rootzone drying irrigation, PRD. The five treatments, 1 - 50% of reduction in water depth (WD) with a frequency alternation of irrigation side (FA) of seven days during the whole production cycle; 2 - 50% of WD and FA of 14 days in the cycle; 3 - 50% of WD and FA of 21 days; 4 - 50% of WD with a fixed irrigation (only one lateral line on one side of the plant); and 5 - full irrigation (two lateral lines with open shutoff valve) throughout the cycle, they were arranged in a randomized block design with five replicates. There is a reduction in photosynthetic rates and water use efficiency as a result of enzymatic impairment or stomatal closure, due to the increased of leaf temperature. The stomatal conductance - *gs* was lower in plants irrigated with 50% of ETc with fixed irrigation in one side of the plant. Even with water deficit in the soil, using the PRD with 50% of ETc, Photosynthesis - *A* Transpiration - *E*; Leaf temperature - *Tleaf*, internal concentration of CO_2 - *Ci*; stomatal conductance - *gs*; photosynthetically active radiation - *Qleaf*; carboxylation efficiency - *A/Ci*; Quantum efficiency of Photosynthesis - *A/Qleaf*; and instantaneous water use efficiency – *WUE* 'BRS Princesa' banana were similar among strategies, highlighting the possibility of use of the irrigation management technique with PRD, saving water, and no physiological changes in the plants.

Key words: Abiotic stress, irrigation techniques, photosynthetic rate, stomatal closure, vegetative growth, water deficit.

Resumen

El objetivo del estudio fue evaluar las características fisiológicas del banano 'Princesa' bajo riego lateralmente alternado (RLA). El diseño experimental fue de bloques al azar, con cinco tratamientos y cinco repeticiones: 1 - reducción del 50% en la lámina de riego (LR) con el lado de frecuencia de la conmutación de la planta (FC) 7 días durante todo el ciclo de producción; 2 - 50% de LR y 14 días de FC en el ciclo; 3 - 50% de LR y FC 21 días; 4 - 50% con un LR de riego fijo (sólo una de las alas en un lado de la planta) y 5 - riego completo (dos líneas laterales con registros abiertos) durante el ciclo. La conductancia estomática - *gs* fue menor en las plantas regadas con 50% de ETc en sistema de riego fijo. Incluso con déficit de agua en el suelo, con el RLA con 50% de ETc, Fotosíntesis –*A*, Transpiración - E; Temperatura de la hoja - *Tl*, la concentración interna de CO_2 - *Ci*; conductancia estomática - *gs*; Radiación fotosintéticamente activa - *Qleaf*; eficiencia de carboxilación - *A/Ci*; La eficiencia cuántica de la fotosíntesis - *A/Qleaf*; y la eficiencia instantánea del uso del agua –*A/E* en el banano 'Princesa' no difiere entre los tratamientos, lo que pone de relieve la importancia de la técnica de gestión de riego, con el ahorro de agua y sin cambios fisiológicos de las plantas.

Palabras clave: Cierre de estomas, crecimiento vegetativo, déficit de agua, estrés abiótico, taza fotosintética, técnicas de riego.

Introduction

With a production of 6.902.184 tons in 2013 (FAO, 2015), Brazil ranks as the fifth largest producer of bananas in the world. The northeastern and southeastern regions account for 66.54% of production. The state of Minas Gerais is the second largest producer, with 40.35% of production concentrated in the North of Minas Gerais (IBGE, 2015), recently identified as Region Jaíba, characterized as semi-arid, with irregular rainfall distribution, annual average of up to 800 mm and aridity index between 0.2 and 0.5 calculated by water balance.

Banana is water demanding and its cultivation productivity tends to increase linearly with transpiration, which in turn depends on the availability of water in the soil, which can be controlled by irrigation (Coelho *et al.*, 2006). The response of the banana in vegetative growth and productivity depends on the local weather conditions which result in a lower or higher evaporation rate, and, consequently, greater flow of sap and photoassimilates. To obtain an economically profitable harvest, a monthly rainfall between 100 and 180 mm month^{-1} is sufficient (Costa *et al.*, 2009). The amount of rainfall of 717 mm and 2438 mm of evapotranspiration of reference are the most appropriate values for banana production in the North of Minas Gerais, Brazil (Borges *et al.*, 2011), which turns the use of irrigation necessary and requires from the producers a precise handling, as the limitation of water is a universal phenomenon and represents major obstacle in the production of banana (Vanhove *et al.*, 2012; Muthusamy *et al.,* 2014), especially in semi-arid regions of the tropics and subtropics (Surendar *et al.*, 2015), more susceptible to climate change.

Silk banana stands out because of the consumer preference and the high value in the Brazilian market. However, their high susceptibility to Panama disease is the major limitation, which made its cultivation in Brazil itnerent with migration to new areas. Recently, the Brazilian Program of Banana Breeding, recommended tetraploid cultivars with resistent Maçã fruit type (Caipira/Yangambi Km5) and tolerant (BRS Tropical and BRS Princesa) to this phytosanitary problem (Silva *et al.*, 2013), with greater dry tolerance and therefore, more adapted to deficit irrigation strategies.

The use of irrigation management strategies that aim at the rational use of water to maximize the water use efficiency and irrigation is the key to a productive and environmental sustainability, especially in semi-arid regions where the availability of water resources does not meet the demand (Santos *et al.*, 2014a). Among these strategies, which increase water use efficiency and are more acceptable from an environmental point of view, stand out the Partial Rootzone Drying (PRD) and Regulated Deficit Irrigation (RDI) (Santos *et al.*, 2013; 2014a; 2014b; Lima *et al.*, 2015), which seem to be more feasible for use in banana cultivars that are more tolerant to soil water deficits, like hybrids (AAAB).

The water conditions of the soil and climate conditions change the water of plants, gas exchange and leaf temperature that influence growth, development and production (Santos *et al.*, 2013). The PRD consists of the alternation of irrigation on two sides of a plant (Santos *et al.*, 2015), where, two halves of the root are alternately irrigated, based on the theoretical assumption that the irrigated root half would maintain the water status of the plant (Lima *et al.*, 2015), with a set frequency, being the most commonly used seven, 14 and 21 days (Kang & Zhang, 2004). The PRD based on biochemical responses of plants for vegetative and reproductive balance by water stress. According to Lima *et al.* (2015), the PRD induced a greater stomatal closure in papaya compared with RDI, for the same water tension in the soil, due to the influence of non-irrigated part of the root zone, where water stress induces higher production of abscisic acid.

These irrigation techniques apply less water than the evapotranspired in a given period, with increase in the application efficiency and reduction in the losses by percolation. Yields may be lower than the maximum, since at acceptable levels, saving water and energy, reductions in operating costs of irrigation, lower leaching of chemicals and increase in the water use efficiency, WUE. Therefore, despite evidences from different studies, the responses of plants are controversial (Lima *et al.*, 2015) and show site specificity depending on changes in soil-water-genotype-atmosphere interactions. Given the above, the aim of the present research was to evaluate physiological characteristics of banana 'BRS Princesa' cultivated under Partial Rootzone Drying Irrigation (PRD).

Material and methods

Study area

The experiment was conducted with 'BRS Princesa' banana (YB42-07), resistant to yellow Sigatoka and tolerant to Panama disease in the first production cycle, with plants spaced 2.0 m x 2.5 m in Experimental Farm of Gorutuba, Epamig Norte, Nova Porteirinha, Minas Gerais, Brazil, under the geographic coordinates 15° 46' 38" S and 43°17' 22" W and altitude of 537meters, soil with 457.5 g kg^{-1} of sand, 247 g kg^{-1} of silt and 295 g kg^{-1} of clay, with average moisture of 0.3628 cm^3 cm^{-3} and 0.2287 cm^3 cm^{-3} to -10 kPa and -1500 kPa, respectively. The climate is BSwh type (Köppen classification), warm weather, with summer rains and dry periods well defined in the winter.

Conduction of the experiment and irrigation management

The plants were irrigated by drip with two lateral lines per row of plants with six emitters per plant, three on each side. Each wing had a shutoff valve at the beginning, to allow irrigation on only one side of the plant when needed.

The five treatments, strategies based on partial root zone drying (PRD), according to Santos *et al.* (2015), 1 - 50% of reduction in water depth (WD) with a frequency alternation of irrigation side (FA) of seven days during the whole production cycle; 2 - 50% of WD and FA of 14 days in the cycle; 3 - 50% of WD with a fixed irrigation (only one lateral line on one side of the plant); and 5 - full irrigation (two lateral lines with open shutoff valve) throughout the cycle, they were arranged in a randomized block design with five repetitions.

The accumulated water depth applied in different treatments were 472.38 mm for irrigation in treatments 1, 2; 3 and 5 and 944.76 mm to the irrigation in the treatment 4 with full irrigation. The evapotranspiration of reference determined during the periods of irrigation, crop coefficient and the depth used in the treatments are listed in Figure 1.

Analyzed Variables

During the production cycle, in five evaluations, the physiological variables were measured with the aid of the infrared gas analyzer (IRGA) Lcpro + Portable Photosynthesis System model (ADC BioScientific Limited, UK) with temperature and environmental irradiance and air flow of 200 ml min^{-1}. They were measured the incidence of radiation in leaf (*Qleaf*) expressed in µmol m^{-2} s^{-1} of photons, leaf temperature (*Tleaf*), internal CO_2 concentration (*Ci*), µmol mol^{-1}, stomatal conductance (*gs*), mol m^{-2} s^{-1}, transpiration (*E*) mmol m^{-2} s^{-1} of H_2O, photosynthesis (*A*) µmol m^{-2} s^{-1} of CO_2, intrinsic water use efficiency (*A/gs*), instantaneous water use efficiency (*A/E*), carboxylation efficiency (*A/Ci*), quantum efficiency of photosynthesis (*A/Qleaf*) and the ratio of between internal concentration (mesophyll) and external (ambient) of CO_2 (*Ci/Cref*).

The measurements taken at the five periods correspond to July 31st; August 30th; September 27th; November 1st and December 6th of 2012. Each month the measurements were taken at two times, 08:00 and 14:00 on the sheet three of plants of the replications.

For statistical analysis of the evaluated characteristics adopted the arrangement in a factorial 5 x 2 x 5, in a randomized block design, five evaluation periods (months), two collection times each season and five PRD irrigation strategies. Submitted the data of *Tleaf, Qleaf, Ci, gs, E, A, A/E, A/Ci* and *A/Qleaf* to analysis

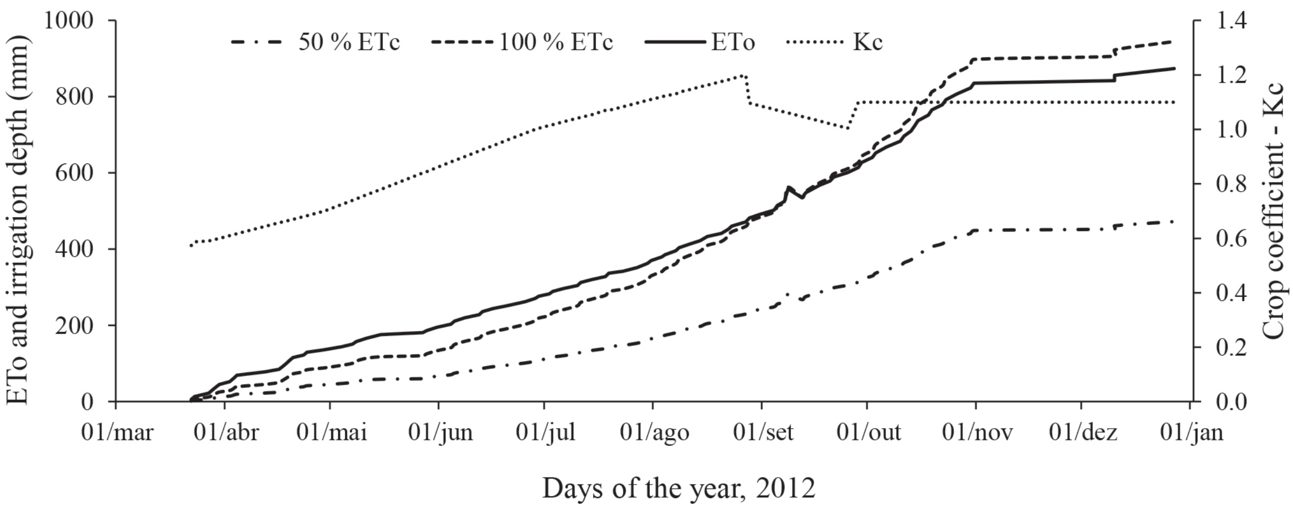

Figure 1. Reference crop evapotranspiration – ETo, crop coefficient – Kc, Accumulated irrigation depth for treatments 1, 2, 3 and 5 (50% ETc) and Treatment 4 (100% ETc).

of variance and proceeded to the deployment of interactions according to their significance; they also compared the averages of these variables by Tukey test (P <0.05) for all factors.

Results and discussion

Photosynthesis – *A*, transpiration – *E*, leaf temperature – *Tleaf*, internal concentration of CO_2 – *Ci*. Stomatal conductance – *gs*; photosynthetically active radiation – *Qleaf*; carboxylation conductance – *A/Ci*; quantum efficiency of photosynthesis – *A/Qleaf*, and instant water-use efficiency - *A/E* in banana plants BRS 'Princesa' were influenced by the season and time of measurement, regardless the strategies of irrigation (Table 1).

Table 1. Photosynthesis – *A;* Transpiration – *E;* Leaf temperature – *Tleaf;* Internal concentration of CO_2 – *Ci;* Stomatal conductance – *gs;* Photosynthetically active radiation incident on the leaf – *Qleaf;* Carboxylation efficiency - *A/Ci;* Quantum efficiency of photosynthesis - *A/Qleaf;* and instant water-use efficiency – *A/E in* banana plants 'BRS Princesa' under different days after the beginning of application of the treatments and times of partial rootzone drying (PRD).

Time	Date (Days after the beginning of application of the treatments)					CV (%)
	31/07(131)	30/08(161)	27/09(189)	01/11(224)	06/12(259)	
			A (µmol of CO_2 m^{-2} s^{-1})			
08:00	18,21 AB a	20,83 A a	18,44 AB a	14,21 C a	17,90 B a	23,82
14:00	17,20 A a	17,20 A b	1,93 B b	14,65 A a	15,26 A b	
			E (mmol of H_2O $m^{-2}s^{-1}$)			
08:00	4,27 C b	7,38 B b	3,67 C a	6,13 B b	8,96 A b	26,49
14:00	9,15 B a	9,15 B a	2,03 C b	10,69 A a	10,69 A a	
			Tleaf (°C)			
08:00	29,28 C b	35,82 B b	29,92 C b	36,84 B b	39,22 A b	4,42
14:00	38,75 D a	38,75 D a	40,46 C a	43,73 A a	42,20 B a	
			Ci (µmol of CO_2 $m^{-2}s^{-1}$)			
08:00	206,20 A a	191,21 B b	187,53 B b	190,21 B b	213,95 A a	8,66
14:00	205,87 B a	205,87 B a	230,68 A a	200,07 B a	220,21 A a	
			gs (mmol of H_2O $m^{-2}s^{-1}$)			
08:00	0,34 BC a	0,42 AB a	0,27 C a	0,27 C a	0,48 A a	40,41
14:00	0,29 AB a	0,39 AB a	0,038 C b	0,34 B a	0,48 A a	
			Qleaf (µmol of photons $m^{-2}s^{-1}$)			
08:00	1.470,85 A b	1.505,23 A a	1.178,09 B b	533,11 C b	1.299,33 AB b	23,90
14:00	1.671,44 A a	1.671,44 A a	1.418,11 B a	1.092,19 C a	1.527,09 AB a	
			A/Ci (µmol de CO_2 $m^{-2}s^{-1}$) (µmol de CO_2 $m^{-2}s^{-1}$)$^{-1}$			
08:00	0,088 BC a	0,110 A a	0,099 AB a	0,075 C a	0,084 BC a	25,05
14:00	0,084 A a	0,084 A b	0,009 B b	0,074 A a	0,070 A b	
			A/Qleaf (*µmol de CO_2* $m^{-2}s^{-1}$) (µmol de fótons $m^{-2}s^{-1}$)$^{-1}$			
08:00	0,014 B a	0,014 B a	0,017 B a	0,027 A a	0,016 B a	36,38
14:00	0,010 B b	0,010 B b	0,001 C b	0,015 A b	0,011 AB b	
			A/E (µmol de CO_2 $m^{-2}s^{-1}$) (mmol de H_2O $m^{-2}s^{-1}$)$^{-1}$			
08:00	4,32 B a	3,01 C a	5,03 A a	2,37 D a	2,18 D a	20,37
14:00	1,94 A b	1,94 A b	0,98 C b	1,38 B b	1,45 B b	

Means followed by different letters, uppercase, compare to the values in the same row and lowercase ones compare the values in the same column differ (P<0.05) by the Tukey's test for each variable.

Tetraploid cultivars with fruits Maçã 'BRS Princesa' and 'BRS Tropical' (AAAB) exhibit lower productive potential, though they appear to have higher tolerance to drought in comparison with the triploid AAB, such as 'Prata-Anã' and AAA, as 'Grande Naine', which may justify the maintenance of gas exchange rate under different strategies of PRD. It is widespread in the literature the information that the presence of genome B of *Musa balbisiana* gives a higher tolerance to stress caused by the shortage of water than the genome A of *Musa acuminate*, which may have a relation to the synthesis of aquaporin, protein that forms canals that are selective in flowing water through the membrane, accumulation of proline and synthesis of abscisic acid (Vanhove *et al.,* 2012).

Banana plants exhibited gas exchanges with a similar behavior in all the assessment periods. The photosynthesis rate, stomatal conductance and carboxylation, photochemical, and water-use efficiencies were higher at 8:00 am, while, the transpiration rate, internal concentration of CO_2, leaf temperature and photosynthetically active radiation measured in banana leaf 'BRS Princesa' were lower in the mentioned time.

The highest *Qleaf* that was observed in the afternoon in all the periods of assessment, exhibited increment in the transpiration rate at 2:00 pm when compared to the one measured at 8:00 am, showing that the reduction in the photosynthesis rate in the afternoon does not happen due to the stomatal closure, which its purpose is mostly maintaining the stomatal conductance in both times (Table 1). Probably the reduction in photosynthesis has better explanation as a consequence of the effect of the temperature on the kinetic of the enzyme rubisco, altering the activity from carboxylase to oxygenase, or as a consequence of changes in permeability of membranes (Taiz & Zeiger, 2013).

The eco-physiological behavior is a result of the balance of several environmental factors and not a single factor. The optimal temperature for the carboxylation of CO_2 by the enzyme rubisco, ribulose-1.5-bisphosphate carboxylase/oxygenase is 22 °C. This enzyme prevails in plants with photosynthetic mechanism C_3, such as the banana plant. The balance between the activities of carboxylase and oxygenase of the rubisco is maintained by the kinetic properties of the enzyme, temperature, and concentration of CO_2 and O_2. Under concentration of environmental CO_2, an increase in the temperature modifies the kinetic constants of the rubisco and increases the oxygenation rate, preferably, the carboxylation (Taiz & Zeiger, 2013), that is, it increases the photorespiration with decrease in the net photosynthesis rate of the plant. In general, below 30 °C, the quantum productivity of the photosynthesis, mol of CO_2 fixed per absorbed quantum, in C_3 plants is usually high and, above this limit, it falls significantly.

The largest change in photosynthetic rate from 8:00 to 14:00 h was recorded in September (Table 1).

The lower rate of photosynthesis measured in this study, 1.93 μmol CO_2 m^{-2} s^{-1} reflects the physiological behavior of the front plant to abiotic stress factors, such as low relative humidity, high vapor pressure deficit, the incidence of high winds speed, high temperature, and the higher temperature range, 10.54 °C, which characterize the period immediately prior to the rainy season in the semi-arid, ie, end of dry cold winter and initiation warm spring. Unlike other times, there was a reduction in transpiration and stomatal conductance, from 8:00 to 14:00 hours, demonstrating the stomatal closure more than the enzymatic impairment as a limitation to photosynthesis, because, usually up to 40 °C transpiration increases linearly with temperature, changing the behavior starting that value.

Some banana cultivars express a thermal regulation mechanism, which is response in terms of tolerance as a result of exposure of tissues, organisms or cells to high or low temperature stress with sudden variations ranging from 5 °C to 10 °C, for instance, synthesis of chaperones (Henry *et al.* 2011), HSPs and synthesis of ABA (Santos *et al.* 2005), identified in *M. acuminata* ssp. *Burmannicoides* var. Calcutá 4 (AA) and HSP70 in roots of plants *in vitro* of banana 'Cachaco' (ABB, ITC 0643) after being under osmotic stress of 0, 1, 4 and 14 days (Vanhove *et al.*, 2015), due to thermal, hydric, osmotic, and oxidative stresses are related to one another (Wang *et al.,* 2003).

Among the analyzed physiological parameters, only the stomatal conductance showed effect of interaction between the factors days after the beginning of application of the treatments and irrigation strategies (Table 2).

Table 2. Stomatal conductance – *gs* in banana 'BRS Princesa' in different days after the beginning of application of the treatments (DAB) and strategies of partial rootzone drying (PRD).

DAB	Irrigation strategy					CV (%)
	PRD50%7D	PRD50%14D	PRD50%21D	50%ETc	FI	
31/07 (131)	0,43 A b	0,34 A ab	0,35 A a	0,39 A a	0,32 A bc	
30/08 (161)	0,37 A b	0,45 A a	0,39 A a	0,44 A a	0,37 A ab	
27/09 (189)	0,16 A c	0,16 A b	0,16 A b	0,15 A b	0,16 A c	40,41
01/11 (224)	0,30 A bc	0,33 A ab	0,33 A ab	0,34 A a	0,29 A bc	
06/12 (259)	0,63 A a	0,49 AB a	0,49 AB a	0,36 B a	0,51 AB a	

Means followed by different letters, uppercase, compare the values in the same row and lowercase ones compare the values in the same column (P<0,05) by the Tukey's test. PRD50%7D - 50% of reduction in water depth (WD) with a frequency alternation of irrigation side (FA) of seven days; PRD50%14D - 50% of WD and FA of 14 days; PRD50%21D - 50% of WD and FA of 21 days; 50%ETc - 50% of WD with a fixed irrigation and FI - full irrigation.

The lowest *gs* for all the irrigation strategies were observed on the 189th day after the beginning of application of the treatments, which coincided with the month of higher stress for banana in this region. The elevated values of *gs* that were observed in other periods explained the high transpiration rates, mainly in the afternoon period, as an evolutionary strategy of the plant to exchange heat.

Taiz & Zeiger (2013), pointed out that the *gs* determines the entry of CO_2 and exiting of water by the stomata; larger the opening, lower the stomatal resistance and, consequently, there is an increase in transpiration. In the present study, even with a decrease in *gs* in irrigated plans with 50% of ETc in fixed irrigation system, a significant increase in transpiration was not verified.

By working with saline stress, fixing calcium and varying the concentration of sodium, Neves *et al.* (2002), found out not significantly differences in *A, gs, E* and *A/E*, in banana 'Prata-Anã', showing the salinity increased which was accomplished by Na solution increasing, did not interfere in the gas exchanges performed by the plants, perhaps by osmotic adjustment, which is associated with the ions Na and K or even with organic solutes and proline in the vacuole (Sudendar *et al.* 2015).

Bananas 'BRS Princesa' cultivated under partial drying or the radicular system exhibited gas exchanges with high positive correlation to transpiration - *E* and leaf temperature - *Tleaf* (Figure 2A), between photosynthesis - *A* and stomatal conductance - *gs* (Figure 2B) and negative correlation between instant water-use efficiency - *A/E* and leaf temperature - *Tleaf* (Figure 2C) at 8:00 am. The evaluation conducted at 2:00 pm registered high positive correlation between photosynthesis – *A* and stomatal conductance - *gs* (Figure 2D) and negative correlation between instant water-use efficiency - *A/E* and leaf temperature -*Tleaf* (Figure 2E).

The instant water-use efficiency decreases as the temperature increases, in which the decrease in the relation *A/E* is related to the increase in temperature. The highest values observed at 8:00 am in this study are related to milder temperatures, 24 °C, whereas, at 2:00 pm, the maximum *A/E,* 3.0 μmol m^2 s^{-1}/ mmol m^2 s^{-1} is related to higher temperatures, 32 °C. The increase in leaf temperature can occur from the increase in the room temperature, which, consequently, caused a drop in instant water-use efficiency - *A/E*, because by increasing the leaf temperature there are enzymatic changes that lead to alterations in membrane permeability (Taiz & Zeiger, 2013), reduction in stomatal conductance and fall in carboxylation efficiency, in the quantum efficiency of photosynthesis and in the photosynthesis, since there is high negative correlation among *Tleaf* and *A/E*.

Conclusion

It is possible to identify reduction in photosynthesis rate as a higher consequence of the enzymatic activity or the stomatal closure. Higher leaf temperature increased transpiration and reduced instant water-use efficiency. The irrigation strategies with PRD maintain the gas exchanges of banana 'BRS Princesa'.

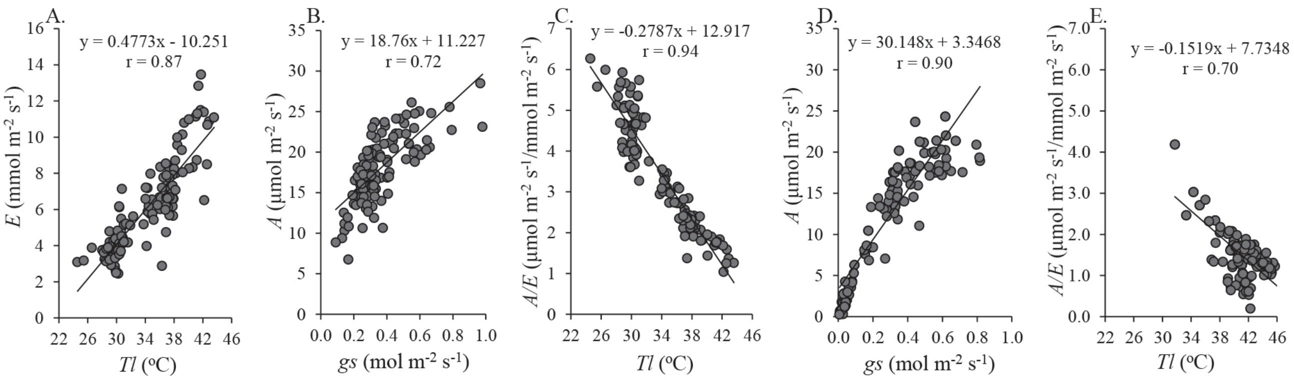

Figure 2. Transpiration - *E* in function of leaf temperature *Tleaf* (A), photosynthesis - A in function of stomatal conductance - *gs* (B) and instant water-use efficiency - *A/E* in function of lead temperature - *Tleaf* (C) measured at 08:00 am and photosynthesis – A in function of stomatal conductance – *gs* (D) and instant water-use efficiency – *A/E* in function of leaf temperature – *Tleaf* (E) measured at 2:00 pm.

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