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Vegetative growth of Conilon coffee plants under two water conditions in the Atlantic region of Bahia State, Brazil

Crescimento vegetativo de plantas de café Conilon sob dois regimes hídricos, na região Atlântica da Bahia, Brasil

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ABSTRACT. Extreme temperatures and persistent water stress stand out among the main factors that restrict the vegetative growth and productivity of *Coffea canephora*. The objective of this study was to evaluate the vegetative growth of orthotropic and plagiotropic branches of *C. canephora* under non-irrigated and irrigated conditions, and their correlation with climatic factors in the Atlantic region of Bahia State, Brazil. The experiment was established with two treatments (non-irrigated and irrigated) in a completely random design with 14 replicates. One orthotropic and four plagiotropic branches were labelled on each plant. During the two-year experimental period, the growth of these branches was evaluated at 14-day intervals. Two harvests were performed to obtain productivity data. In summary, it was confirmed that irrigation resulted in an increased productivity of Conilon coffee in the Atlantic region of Bahia, Brazil. The growth rate of the orthotropic and plagiotropic branches was higher in irrigated plants. The growth rate of the plagiotropic branches was limited by the fruit load capacity. The growth rate of *C. canephora* branches was not limited by the minimum average air temperature in the Atlantic region of Bahia, Brazil.

Keywords: *Coffea canephora*, water deficit, temperature, plagiotropic branches.

RESUMO. Temperaturas extremas e o deficit hídrico prolongado destacam-se como os fatores limitantes ao crescimento vegetativo e à produtividade de *Coffea canephora*. O objetivo foi avaliar o crescimento vegetativo de ramos ortotrópicos e plagiotrópicos de *C. canephora* em condições não irrigadas e irrigadas, e relacioná-lo com os fatores climáticos, na região Atlântica da Bahia. O experimento foi instalado com dois tratamentos (não irrigado e irrigado), no delineamento inteiramente casualizado, com 14 repetições. Marcou-se um ramo ortotrópico e quatro ramos plagiotrópicos em cada planta. O crescimento desses ramos foi avaliado em intervalos de 14 dias, durante dois anos. Foram realizadas duas colheitas para obtenção da produtividade. Em resumo, foi confirmado que a irrigação resultou em aumento de produtividade de café Conilon na região Atlântica da Bahia. A taxa de crescimento dos ramos ortotrópicos e plagiotrópicos com carga pendente é superior nas plantas irrigadas. A taxa de crescimento de ramos plagiotrópicos é limitada pela carga pendente. A taxa de crescimento dos ramos de *C. canephora* não é limitada pela temperatura mínima média do ar predominante na região Atlântica da Bahia.

Palavras-chave: *Coffea canephora*, deficit hídrico, temperatura, ramos plagiotrópicos.

Introduction

The genus *Coffea* comprises at least 124 species, of which *Coffea arabica* and *C. canephora* are economically important (Davis, Tosh, Ruch, & Fay, 2011). Despite *C. arabica* being the most widely farmed species in the world, the cultivation of *C. canephora* (Conilon coffee) has significantly contributed to coffee production worldwide. In 2015, world coffee production exceeded 144.7 million bags, of which 41.5% were Conilon coffee produced in countries considered as emerging, with Brazil being the second largest producer of this species worldwide (International Coffee Organization [ICO], 2016).

The species *C. canephora* is cultivated in the Atlantic region of Brazil, where it represents an important source of income in many counties. With the availability and implementation of efficient technologies for coffee production, this region has shown a considerable increase in production and productivity in the last few years. However, despite technological advances and apparently favourable climatic conditions for coffee farming within this region, coffee growth, development and productivity have been jeopardized by water deficits and extreme or inadequate temperatures that differ from those considered suitable for its cultivation (DaMatta & Ramalho, 2006).

Temperatures below 13°C and accentuated water deficits affect diverse components of the photosynthetic process because they reduce stomatal conductance, net photosynthesis, the photochemical efficiency of photosystem II, the efficiency of the electron transport chain in the thylakoid membrane, enzymatic activity and carbon metabolism, in addition to modifying the composition and structure of the photosynthetic pigment complexes, lipids and fatty acids, with different intensities recorded for different genotypes and species (Batista-Santos et al., 2011; Ferreira, Partelli, Didonet, Marra, & Braun, 2013; Partelli, Marré, Falqueto, Vieira, & Cavatti, 2013; Scotti-Campos, Pais, Partelli, Batista-Santos, & Ramalho, 2014). On the other hand, high air temperatures may cause the denaturation and aggregation of proteins as well as an increase in the production of reactive oxygen species (DaMatta & Ramalho, 2006), ethylene synthesis and evaporative demand, which may result in stomatal closing and a reduction in the supply of CO_2, which consequently reduces net photosynthesis (Vara Prasad, Allen Júnior, & Boote, 2005) and the production of coffee beans (Craparo, Asten, Laderach, Jassogne, & Grab, 2015; Ovalle-Rivera, Laderach, Bunn, Obersteiner, & Schroth, 2015). When cultivated at temperatures below 17°C or above 31°C, Conilon coffee shows an expressive reduction in the growth rate, which negatively impacts production (Partelli et al., 2013).

A water deficit may be considered a limiting factor for coffee plant growth because the majority of cultivated areas are located in regions with water restrictions (Araújo, Reis, Moraes, Garcia, & Nazário, 2011). Consequently, the farming of Conilon coffee has been conducted predominantly under irrigation because this condition enhances the production of flower buds (Carvalho, Colombo, Scalco, & Morais, 2006), increases the number of plagiotropic branches per plant (Nazareno et al., 2003), enhances the number of flowers per plant (Massarirambi, Chingwara, & Shongwe, 2009) and results in better development and grain formation (Pezzopane, Castro, Pezzopane, Bonomo, & Saraiva, 2010). Therefore, irrigation guarantees high productivity (Bonomo et al., 2013; Sakai et al., 2015) and a final product with a better beverage quality (Fernandes, Partelli, Bonomo, & Golynski et al., 2012).

Climate change represents another limiting factor for coffee production and is responsible for the loss of areas suitable for the cultivation of *C. arabica* and *C. canephora* worldwide (Bunn, Laderach, Rivera, & Kirschke, 2015). The loss of suitable areas for Conilon is significant in Brazil and Vietnam. According to Bunn et al. (2015), Conilon coffee may substitute the farming areas of *C. arabica* due to its tolerance to high temperatures. Nevertheless, this scenario may only be feasible in some regions where Conilon coffee develops better (regions with low intra-seasonal variability). The Furthermore, the sensitivity of Conilon coffee to climate changes is prominent at lower latitudes and altitudes (Bunn et al., 2015).

By studying the physiological and biochemical responses of photosynthesis to elevated atmospheric CO_2 concentration and/or temperature in several *C. arabica* and *C. canephora* genotypes, Rodrigues et al. (2016) demonstrated that predictions concerning the impacts of climate change and global warming should consider the role of CO_2 as a key player in coffee heat tolerance. They also demonstrated a relevant heat resilience of coffee species and showed that an elevated CO_2 concentration remarkably mitigated the impact of heat on coffee physiology. In this regard, and fortunately, future perspectives on the sustainability of the coffee crop that are based on increasing temperature scenarios should not be as catastrophic as previously predicted (Rodrigues et al., 2016).

An understanding of the seasonal fluctuations of *C. canephora* vegetative growth under non-irrigated and irrigated conditions, associated with the climatic conditions within particular growth areas, is an important tool for plant evaluation because it has direct implications for the irrigation management and planning of nutritional programmes of coffee plantations. Unfortunately, references that are currently available on this subject are scarce.

Consequently, the objective of this study was to evaluate the vegetative growth of orthotropic and plagiotropic branches of *C. canephora* under irrigated and non-irrigated conditions, and associate this with the climatic factors of the Atlantic region of Bahia State, Brazil.

Material and methods

The experiment was performed in a commercial plantation in Itabela county, Southern Bahia State, Brazil, at an altitude of 108 m, a latitude of 16°42’13” South and a longitude of 39°25’28” West. The climate was classified as Aw, i.e., tropical with a dry winter season winter and a rainy summer season (Alvares et al., 2013). Three-year-old *Coffea canephora* plants from the clonal variety Emcapa 8111, 'genotype 02' (Bragança, Carvalho, Fonseca, & Ferrão, 2001), which were cultivated in full sunlight, with a 3.5 x 1.0-m spacing and supplied with fertigation since the seedling transplant, were used in the experiment. The plantation was established with four productive stems per plant under a cyclic pruning programme. However, the plantation was evaluated before the pruning stage was reached. Additional cultural treatments were performed according to the technical recommendations for coffee plantations.

The plants were grown in soil classified as a Yellow Latosol (Oxisoil), originally dystrophic with a sandy loam texture (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 2013) and the following chemical and physical characteristics at a depth of 0-20 cm: pH = 6.25; available P, K, S, B, Cu, Fe, Mn, and Zn contents of 28.5, 105, 15.5, 1.49, 1.9, 450, 20, and 4.2 mg dm^{-3}, respectively; Ca and Mg contents of 4.15 and 1.55 $cmol_c$ dm^{-3}, respectively; potential acidity (H+Al) of 2.85 $cmol_c$ dm^{-3}; organic matter content of 4.55 dag kg^{-1}; sand, silt and clay contents of 730, 110, and 160 g kg^{-1}, respectively; and a volumetric content at field capacity and a permanent wilting point of 0.19 and 0.13 cm^3 cm^{-3}, respectively.

The experimental design was completely random and was based on a split-plot design in time, with 14 replicates. The treatments consisted of irrigated and non-irrigated coffee plants within the main plot and branches measured at different periods within the split-plots. The non-irrigated treatment was established by withholding irrigation, four months before the evaluations were started, to allow the plants to acclimate to the water deficit. In the irrigated treatment, a surface dripping system was used, with one line of emitters per plant row, with a 0.5-m spacing and a flow rate of 2.0 L h^{-1}. Both treatments received dosages of 500, 100, and 400 kg ha^{-1} $year^{-1}$ of N, P and K, respectively, according to the needs of each phenological stage of the coffee plant. In the irrigated treatment, fertigation was performed weekly, while in the non-irrigated treatment, the fertilizers were applied on the soil surface under the coffee plant canopy and the total amount was partitioned over five application times within one year (September, November, January, March and June).

The maximum, average and minimum temperature, global solar radiation, rainfall and relative humidity of the air were collected at an automatic weather station located at a distance of 800 m from the experimental area (Figure 1). The meteorological data were used to determine the reference evapotranspiration (ETo) according to the Penman-Monteith model (Allen, Pereira, Raes, & Smuth, 1998). To manage irrigation, the daily water balance was used based on the crop evapotranspiration (ETc = ETo $_X$ Kc), the measured local rainfall and the soil water storage characteristics. A daily soil water balance (for both irrigated and non-irrigated conditions) was calculated to identify water deficit periods (Figure 1).

On July 28th 2011, one orthotropic (its terminal portion) and two plagiotropic branches per plant were randomly labelled: an old plagiotropic-bearing branch with 12 productive nodes and two completely expanded leaves per node (PlagBB) and the last-released plagiotropic branch within the orthotropic branch (PlagN1). The orthotropic branch (Orto) was marked from its insertion in the branch PlagBB to the apex. In a similar way, in the next year (2012), the two newest plagiotropic branches from the upper orthotropic branch were also labelled: one on January 28th (PlagN2) and the other on April 29th (PlagN3). These two additional plagiotropic branches were, measured due to the loss of strength of the previously–labelled branches (Partelli, Vieira, Silva, & Ramalho, 2010). The length of these branches was recorded at intervals of approximately 14 days during a two-year period (until July 30th 2013). The total growth of each branch was calculated as the difference between the last and the first measurements. In addition, the daily absolute growth ratio was calculated using a relationship based on the difference between the final and initial branch measurements divided by the number of days between the measurements.

To assess the coffee production per plant, two manual harvests were performed in April 2012 and 2013, using the 14 labelled plants within each treatment. The average production of the coffee grains was quantified in litres (L) of fruit *in natura* per plant. After the first harvest, the PlagBB branch was eliminated by pruning and therefore once it lost its bearing capacity for the next harvest period. In a similar manner, the PlagN1 branch was eliminated after the second harvest.

The vegetative growth and production data were subjected to variance analysis ($p < 0.05$) and the mean values were compared using a t test ($p < 0.05$). The statistical analysis was performed using the ASSISTAT 7.7 Beta software (Silva, 2015). The mean value and standard error were calculated for each variable to be included in the graphics.

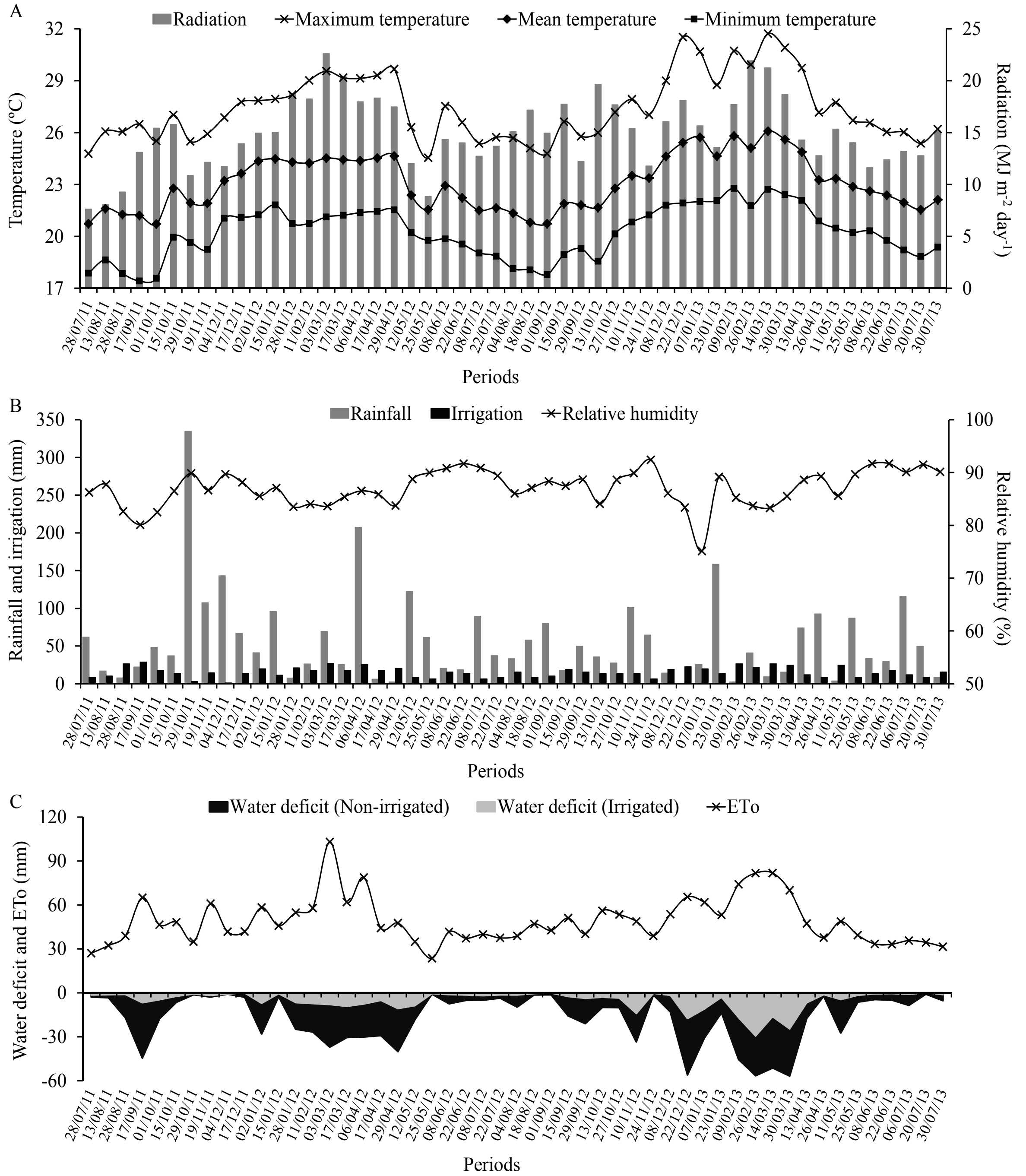

Figure 1. Global solar radiation, maximum, mean and minimum air temperatures (A); rainfall, irrigation and relative humidity (B); water deficit (in non-irrigated and irrigated treatments) and total reference evapotranspiration (ETo) (C), determined during the experimental period between July 2011 and July 2013.

Results and discussion

Under the irrigated treatment, the coffee plants showed greater total vegetative growth in all branch categories, with the exception of PlagN3, which showed a growth pattern similar to the non-irrigated plants (Table 1). The total growth of the orthotropic branches of the irrigated coffee plants was 31.4% higher than that of the non-irrigated coffee plants. Irrigation increased the vegetative growth of PlagBB, PlagN1 and PlagN2 by 68.1, 35.1 and 34.5%, respectively, compared with the non-irrigated coffee plants (Table 1). The lowest total growth was observed for PlagBB, within the non-irrigated treatment (Table 1). The total growth of the plagiotropic branches (PagN1 and PlagN2) was similar to that of the orthotropic branches.

In the Atlantic region of Bahia, Brazil, the growth pattern of the orthotropic and plagiotropic branches of *C. canephora* was not determined by the minimum air temperature (Figures 2, 3 and 4). This is in contrast to the States of Espírito Santo (Partelli et al., 2013) and Rio de Janeiro (Partelli et al., 2010) because the average minimum air temperature, even during the winter period, always remained above 17°C in the present study (Figure 1A). It has been demonstrated that *C. canephora* plants growing at latitudes higher than 15°S show higher vegetative growth rates during periods with longer, hotter days and higher rainfall, while low vegetative growth rates are observed during periods with colder and shorter days (Nazareno et al., 2003; Partelli et al., 2010). *Coffea canephora* plants can endure higher temperatures than *C. arabica* (Ramalho et al., 2014); however, they are less adapted to low temperatures (DaMatta & Ramalho, 2006; Batista-Santos et al., 2011; Ramalho et al., 2014; Scotti-Campos et al., 2014).

The irrigated plants showed a higher growth rate with respect to the orthotropic branch compared with the non-irrigated plants, and the growth pattern of this branch type differed slightly between the evaluation years (Figure 2). The whole area was originally irrigated and the application of mineral nutrients was achieved via fertigation. Consequently, the plants needed to adjust to the water deficit condition resulting from the management modifications imposed to evaluate the non-irrigated condition (Figure 1C). This probably jeopardized the growth rate, even under temperatures that were adequate for growth.

Different coffee genotypes have different adaptation mechanisms for water stress, for example, an increase in stomatal control and the efficiency of water extraction from the soil (DaMatta, & Ramalho, 2006), a deepening of the root system (Pinheiro et al., 2005), and a reduction in leaf area (Cai et al., 2007) and vegetative growth (DaMatta, & Ramalho, 2006), which consequently results in a reduction in photoassimilate production (Sakai, Barbosa, Silveira, & Pires, 2015).

Table 1. Total length of the orthotropic branch (Orto), plagiotropic bearing branch (PlagBB) and new plagiotropic branches (PlagN1, PlagN2 and PlagN3) between July 2011 and July 2013.

Treatment	Total growth (cm)				
	Orto	PlagBB	PlagN1	PlagN2	PlagN3
Non-irrigated	46.1 b*	11.6 b	41.0 b	38.6 b	35.1 a
Irrigated	60.6 a	19.5 a	55.4 a	51.9 a	41.4 a
CV (%)	18.3	43.3	27.6	18.7	27.7

*Mean values followed by the same letter within a column are not significantly different according to the *t* test at a 5% probability level.

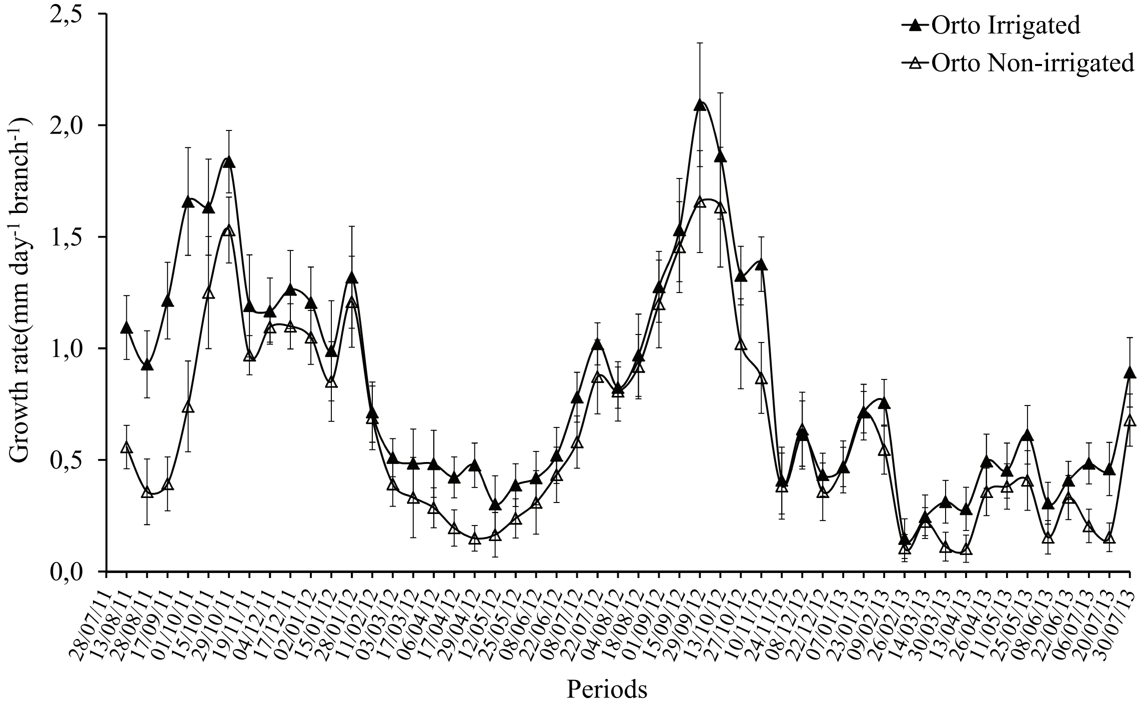

Figure 2. Absolute growth rate of orthotropic branches (Orto) of *Coffea canephora* as a function of the water regime (non-irrigated and irrigated) between July 2011 and July 2013. The graph was plotted using the mean ± mean standard error.

During the first year, higher growth rates were observed during the period from October 2011 to January 2012, while during the second year, higher growth rates were observed during the period from July/August to November 2012 (Figure 2). Within these periods, it is possible to observe a temperature increase in the region, i.e., 3.0 to 5.0°C in the average maximum and minimum temperatures, respectively (Figure 1A), compared with the winter temperatures. According to Partelli et al. (2010), the vegetative growth rate of *C. canephora* cultivated in the North Fluminense region of the Rio de Janeiro State indicates a linear increment as a function of the temperature increase (end of winter and during spring), a condition that is also observed in different genotypes in the Northern region of the Espírito Santo State (Partelli et al., 2013).

In the Atlantic region of the Bahia State, an average maximum temperature above 29.0°C and a water deficit of -30.0 mm (Figure 1) coincided with periods of low vegetative growth of the coffee plants, from February until April 2012, and during December 2012 and April 2013, but without stopping branch growth. During the second harvest, daily maximum temperatures between 34 and 36°C were observed (Figure 1A), mainly on March 11, 13 and 28th, 2013, and April 6th, 2013, corresponding to a period of low vegetative growth (Figure 2). Maximum air temperatures above 31°C result in reduced vegetative growth of *C. canephora* (Partelli et al., 2013).

After the coffee fruits were harvested, which was completed at the end of April 2012 and 2013, the growth rate of the branches remained low (Figures 2, 3, and 4). This may be associated with the stress induced by fruit harvesting, due to the pruning of the non-bearing plagiotropic branches and to sprout thinning procedures.

Higher vegetative growth of the plagiotropic branches occurred between spring and summer (Figure 3 and 4), a period characterized by high rainfall indexes, a gradual increase in temperature within non-limiting levels and a higher availability of light (Figure 1). From the end of October 2011, the PlagBB branch showed a gradual reduction in the net growth rate, until it was approximately equal in both treatments, in the period preceding the harvest (Figure 3). This result was certainly associated with the grain formation stage of the coffee plants, when the requirement for nutrients is high. As fruits constitute preferential sinks for nutrients and photoassimilates (Laviola et al., 2008; Partelli, Espindola, Marré, & Vieira, 2014), vegetative growth is severely jeopardized during this stage, due to an accentuated imbalance in the source:sink ratio of these productive branches, despite these branches (PlagBB) possessing limited autonomy in the production and supply of carbohydrates, as verified for *C. arabica* (Chaves, Martins, Batista, Celin, & DaMatta, 2012). Additionally, the advent of new branches (budding) may reduce the growth of older branches (Ferreira et al., 2013) due to the changes in the source:sink relationship among different branches.

Consistent with the results and discussion above, it was verified that a gradual reduction in the net growth rate from January to March could be observed in the orthotropic branches (Figure 2) and in PlagN1 (Figure 3). However, these branches maintained a considerably high net growth rate, which was not observed in PlagBB (Figure 3). Therefore, the fruiting branches did not lose their growth potential, reinforcing the fact that reproductive growth limits vegetative growth. In fact, Amaral, Rena and Amaral (2006) demonstrated that the growth rate of plagiotropic branches of *C. Arabica* decreased during a period from the end of summer to the end of autumn, for both bearing and non-bearing branches. Nevertheless, these authors also demonstrated that the net growth rates were always higher for the defruited branches.

The PlagN1 branches showed higher net growth rates during the first evaluated period (July 28th, 2011 to July 7th, 2012) compared with the second period (July 22th, 2012 to July 30th, 2013) (Figure 3). This is because these branches did not produce fruit during the first year, in contrast to the second year of evaluation. This behaviour demonstrates that the phenological cycle of coffee has a succession of vegetative and reproductive stages, which occurs within a period of approximately two years (Pezzopane, Pedro Júnior, Camargo, & Fazuoli, 2008).

The growth curves of the PlagN2 and PlagN3 branches indicated similar behaviour during the whole experimental period, with the highest growth values occurring during the spring, between early September and the end of October 2012 (Figure 4). The higher growth values observed from the beginning of November until the end of December 2012, and from the end of January until early April 2013 may be associated with the low amount of rainfall and hence the water deficit, increased temperatures and solar radiation, and the decrease in relative humidity, which was the main driving factor (Figure 1). As the response pattern and the magnitude of the values were similar among the treatments, it may be suggested that the water deficit played less of a role in controlling the growth rates. Nevertheless, with the increase in rainfall amounts recorded in January 2013, the growth rates of the orthotropic and plagiotropic branches showed a small increase (Figures 2, 3 and 4). This means that *C. canephora* responded to the rainfall, a similar behaviour to that observed by Ferreira et al. (2013) for *C. arabica* in the Cerrado Goiano region.

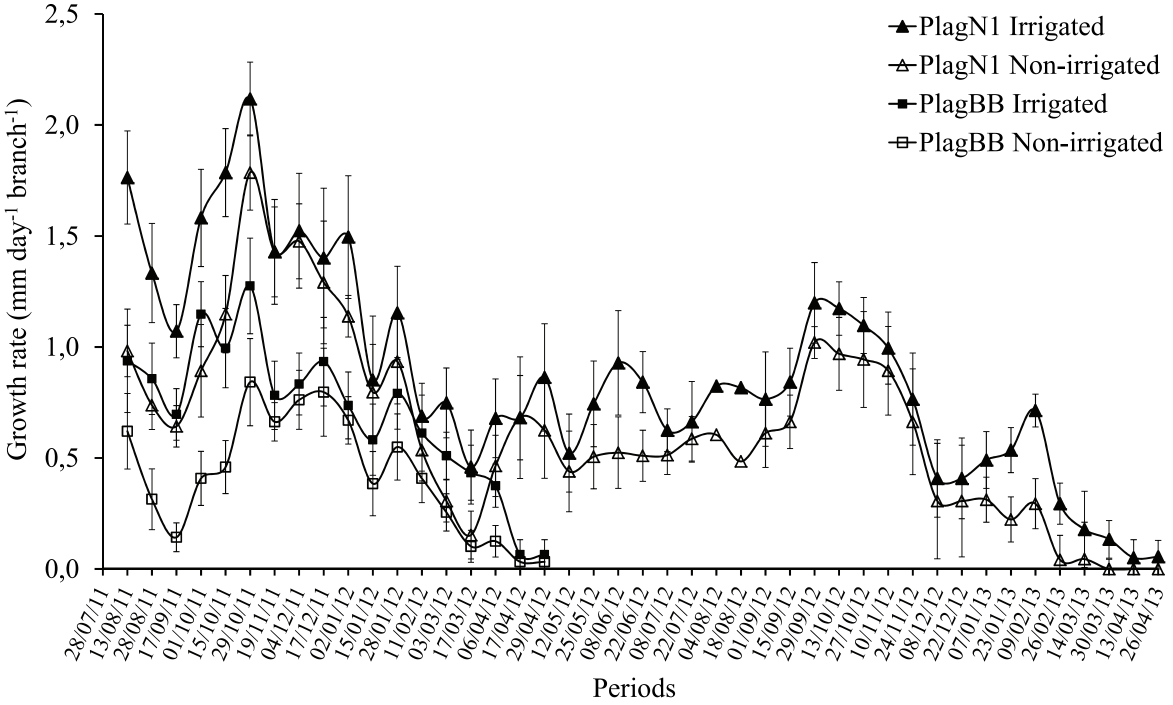

Figure 3. Absolute growth rate of plagiotropic bearing branches (PlagBB) and new plagiotropic branches (PlagN1) of *Coffea canephora,* as a function of the water regime (non-irrigated and irrigated) between July 2011 and July 2013. The graph was plotted using the mean ± mean standard error.

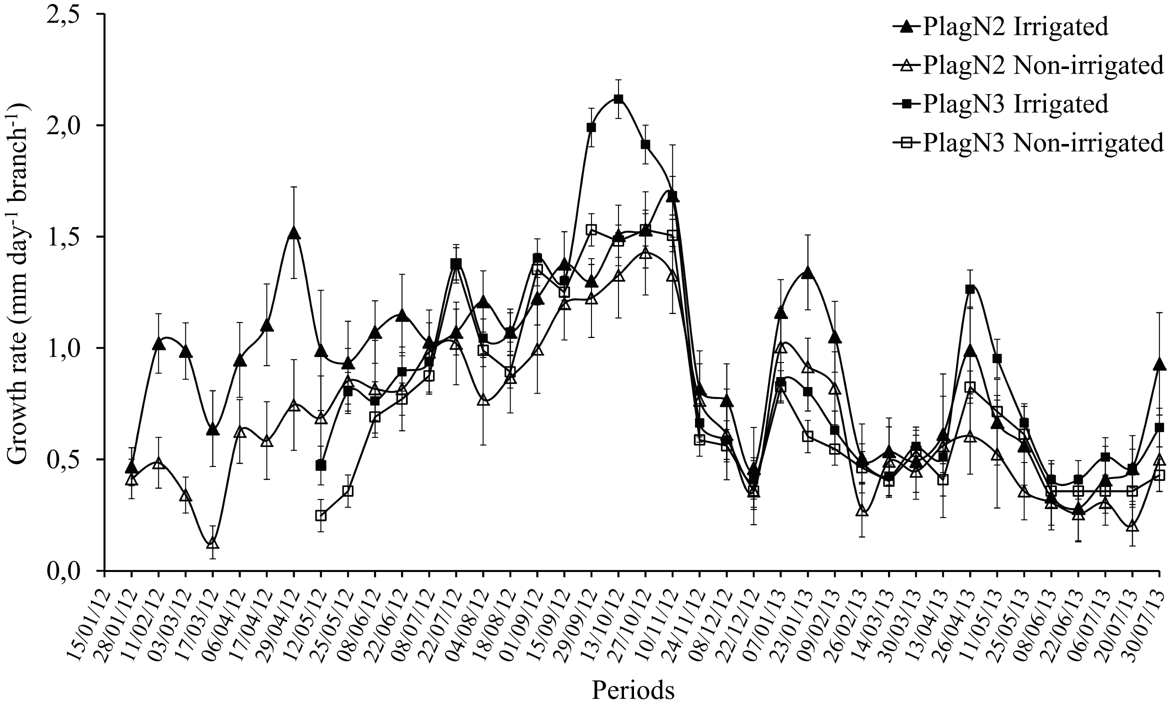

Figure 4. Absolute growth rate of new plagiotropic branches (PlagN2 and PlagN3) of *Coffea canephora,* as a function of the water regime (non-irrigated and irrigated) between July 2011 and July 2013. The graph was plotted using the mean ± mean standard error.

The effect of the water deficit could also be observed on the irrigated plants; however, this effect was lower compared with the non-irrigated plants (Figure 1C). This suggests that the irrigation system used may not have met the water demand of this coffee crop and would need to be configured according to the climatic conditions of the region and the physical characteristics of the soil. According to Soares, Mantovani, Rena, and Soares (2005), a reduction in coffee branch growth results in a lower production of available nodes for bud formation, which consequently reduces fruit production. According to DaMatta (2004), a water deficit affects the development of coffee plant shoots and reduces the leaf area. Further, a reduction in stomatal opening ultimately results in lower CO_2 absorption and a reduction in the photosynthetic rate. A water deficit is the main environmental factor affecting agricultural production in Brazil (DaMatta, Ronchi, Maestri, & Barros, 2010). According to Silva, Cavatte, Morais, Medina, and DaMatta (2013), short water deficit periods may substantially reduce coffee production.

There was no significant difference in the coffee production per plant between the water treatments for the 2012 harvest. Average yields of 22.7 and 22.0 L plant^{-1} were observed in the irrigated and non-irrigated treatments, respectively. However, in 2013, the irrigated plants produced 86.3% more coffee than the non-irrigated plants, resulting in values of 16.1 and 8.6 L plant^{-1}, respectively. It must be emphasized that the branches of non-irrigated plants that produced coffee in the 2012 harvest period were formed in the previous year (this occurs naturally in coffee plants – DaMatta, Ronchi, Maestri, & Barros, 2007), i.e., prior to the suppression of irrigation. As these branches were already completely developed and considering that during the critical period of grain formation, water availability was apparently adequate to guarantee fruit formation (due to adequate rainfall – Figure 1B), the suppression of irrigation did not affect the coffee yield potential. The higher yield of the irrigated plants observed in the second harvest period could be attributed mainly to the high total vegetative growth of PlagN1 (Table 1) because these branches would only produce coffee grains in the second harvest period.

The biennial coffee production effect could be observed in 2013. A biennial cycle is a characteristic of coffee plants that occurs predominantly, and it is associated with excessive fruit yield in the previous year, as evidenced in the 2012 harvest period. The excessive production results in a depletion of plant reserves, affecting growth in the subsequent year (Jaramillo-Botero, Santos, Martinez, Cecon, & Fardin, 2010) and producing alternate cycles of high and low production in coffee plants. Biennial cycling is a naturally occurring process in coffee plants, and not even procedures such as irrigation are able to modify this behaviour (DaMatta et al., 2007), as verified in the present study.

During the period of low production, coffee plants recover their productive capability because the quantity of energy consumed in the process of fructification is small, and the energy supply is focused on vegetative growth and bud differentiation (Sakai, Barbosa, Silveira, & Pires, 2015). In the second harvest period (2013), plants without irrigation showed a coffee reduction of 7.5 L plant^{-1} compared with those that were irrigated. This reinforces the importance of using irrigation with fertilization in *C. canephora* farming in the Atlantic region of the Bahia State.

Irrigation has a positive effect on coffee growth (Nazareno et al., 2003; Ferreira et al., 2013) with respect to the size and quality of the grains (Sakai, Barbosa, Silveira, & Pires, 2013), as well as the yield (Bonomo, Bonomo, Partelli, Souza, & Magiero, 2013; Sakai et al., 2015). Increased coffee plant yield resulting from higher water availability in the soil provided by irrigation is also associated with greater development of the vegetative parts of the plant canopy (Alves, Faria, Guimarães, Muniz, & Silva, 2000), especially the yield components of coffee plants, such as the number of branches per plant, number of nodes per branch, number of fruits per node and dry mass per fruit (DaMatta et al., 2007).

The treatment supplied with irrigation throughout the whole experimental period also showed a reduction in the growth of the orthotropic and plagiotropic branches during periods with high temperature and evapotranspiration, as well as under water deficit conditions that resulted from low rainfall and insufficient irrigation to satisfy the evaporative demand. However, the irrigated plants exhibited the highest rates of vegetative growth compared with the non-irrigated plants during the various evaluations periods. Similar results were reported by Nazareno et al. (2003), Carvalho et al. (2006), Ferreira et al. (2013) and Sakai et al. (2015) for *C. arabica*.

The mean interval period of 14 days between branch growth evaluations was not adequate to conclude which climatic factor is correlated with or explains the behaviour of the vegetative growth of branches of non-irrigated and irrigated Conilon coffee plants because pronounced climatic fluctuations occurred in a short time period in the region under study. Consequently, shorter intervals (weekly or daily) are necessary between branch evaluations to better characterize the behaviour of the seasonal vegetative growth of *C. canephora* as a function of the climatic variables in the Atlantic region of the Bahia State.

Conclusion

Irrigation increased Conilon coffee plant yield in the Atlantic region of Bahia State, Brazil, without changing the biennial pattern.

The growth rate of the orthotropic and plagiotropic branches was higher under irrigation compared with the non-irrigated plants.

The growth rate of the plagiotropic branches depended on their load-bearing capacity.

The maximum growth rates occurred during spring and the minimum growth rates occurred during the endosperm formation period and/or during periods of water deficit, high temperature and low relative humidity.

The growth rate of *C. canephora* branches was not limited by the prevailing average minimum temperatures of the Atlantic region in Bahia, Brazil.

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References

Allen, R. G., Pereira, L. S., Raes, D., & Smuth, M. (1998). *Crop Evapotranspiration: Guidelines for computing crop water requirements* (Irrigation and Drainage Paper 56). Rome: FAO.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., Sparovek, G. (2013). Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6), 711-728. doi: 10.1127/0941-2948/2013/0507

Alves, M. E. B., Faria, M. A., Guimarães, R. J., Muniz, J. A., & Silva, E. L. (2000). Crescimento do cafeeiro sob diferentes lâminas de irrigação e fertirrigação. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *4*(2), 219-225. doi: 10.1590/S1415-43662000000200015

Amaral, J. A. T., Rena, A. B., & Amaral, J. F. T. (2006). Crescimento vegetativo sazonal do cafeeiro e sua relação com fotoperíodo, frutificação, resistência estomática e fotossíntese. *Pesquisa Agropecuária Brasileira*, *41*(3), 377-384. doi: 10.1590/S0100-204X2006000300002

Araújo, G. L., Reis, E. F., Moraes, W. B., Garcia, G. de O., & Nazário, A. A. (2011). Influência do déficit hídrico no desenvolvimento inicial de duas cultivares de café conilon. *Irriga*, *16*(2), 15-124. doi: 10.15809/irriga.2011v16n2p115

Batista-Santos, P., Lidon, F. C., Fortunato, A., Leitão, A. E., Lopes, E., Partelli, F., ... Ramalho, J. C. (2011). The impact of cold on photosynthesis in genotypes of *Coffea* spp. photosystem sensitivity, photoprotective mechanisms and gene expression. *Journal of Plant Physiology*, *168*(8), 792-806. doi: 10.1016/j.jplph.2010.11.013

Bonomo, D, Z., Bonomo, R., Partelli, F. L., Souza, J. M., & Magiero, M. (2013). Desenvolvimento vegetativo do cafeeiro Conilon submetido a diferentes lâminas de irrigação. *Revista Brasileira de Agricultura Irrigada*, 7(2), 157-169. doi: 10.7127/RBAI.V7N200008

Bragança, S. M., Carvalho, C. H. S., Fonseca, A. F. A., & Ferrão, R. G. (2001). Variedades clonais de café conilon para o estado do Espírito Santo. *Pesquisa Agropecuária Brasileira*, *36*(5), 765-770. doi: 10.1590/S0100-204X200100 0500006

Bunn, C., Laderach, P., Rivera, O. O., & Kirschke, D. (2015). A bitter cup: climate change profile of global production of Arabica and Robusta coffee. *Climatic Change*, *129*(1), 89-101. doi: 10.1007/s10584-014-1306-x

Cai, C. T., Cai, Z. Q., Yao, T. Q., & Qi, X. (2007). Vegetative growth and photosynthesis in coffee plants under different watering and fertilization managements in Yunnan, China. *Photosynthetica, 45*(3), 455-461. doi: 10.1007/s11099-007-0075-4

Carvalho, C. H. M., Colombo, A., Scalco, M. S., & Morais, A. R. (2006). Evolução do crescimento do cafeeiro (*Coffea arabica* L.) irrigado e não irrigado em duas densidades de plantio. *Ciência e Agrotecnologia*, *30*(2), 243-250. doi: 10.1590/S1413-7054200600020 0008

Chaves, A. R. M., Martins, S. C. V., Batista, K. D., Celin, E. F., & DaMatta, F. M. (2012). Varying leaf-to-fruit ratios affect branch growth and dieback, with little to no effect on photosynthesis, carbohydrate or mineral pools, in different canopy positions of field-grown coffee trees. *Environmental and Experimental Botany,* 77(1), 207-218. doi: 10.1016/j.envexpbot.2011.11.011

Craparo, A. C. W., Asten, P. J. A., Laderach, P., Jassogne, L. T. P., & Grab, S. W. (2015). *Coffea arabica* yields decline in Tanzania due to climate change: Global implications. *Agricultural and Forest Meteorology*, *207*(1), 1-10. doi: 10.1016/j.agrformet.2015.03.005

DaMatta, F. M. (2004). Exploring drought tolerance in coffee: a physiological approach with some insights for plant breeding. *Brazilian Journal of Plant Physiology*, *16*(1), 1-6. doi: 10.1590/S1677-04202004000100001

DaMatta, F. M., & Ramalho, J. D. C. (2006). Impacts of drought and temperature stress on coffee physiology and production: a review. *Brazilian Journal of Plant Physiology*, *18*(1), 55-81. doi: 10.1590/S1677-04202006000100006

DaMatta, F. M., Ronchi, C. P., Maestri, M., & Barros, R. S. (2007). Ecophysiology of coffee growth and production. *Brazilian Journal of Plant Physiology*, *19*(4), 485-510. doi: 10.1590/S1677-04202007000400014

DaMatta, F. M., Ronchi, C. P., Maestri, M., & Barros, R. S. (2010). Coffee: environment and crop physiology. In DaMatta, F. M. (Ed.), *Ecophysiology of Tropical Tree Crops* (p. 181-216). New York, USA: Nova Science Publishers.

Davis, A. P., Tosh, J., Ruch, N., & Fay, M. F. (2011). Growing coffee: *Psilanthus* (Rubiaceae) subsumed on the basis of molecular and morphological data implications for the size, morphology, distribution and evolutionary history of *Coffea*. *Botanical Journal of the Linnean Society*, *167*(4), 357-377. doi: 10.1111/j.1095-8339.2011.01177.x

Empresa Brasileira de Pesquisa Agropecuária [Embrapa]. (2013). *Sistema brasileiro de classificação de solos*. Rio de Janeiro, RJ: Centro Nacional de Pesquisa de Solos.

Fernandes, A. L. T., Partelli, F. L., Bonomo, R., & Golynski, A. (2012). A moderna cafeicultura dos cerrados brasileiros. *Pesquisa Agropecuária Tropical*, *42*(2), 231-240. doi: 10.1590/S1983-40632012000200015

Ferreira, E. P. de B., Partelli, F. L., Didonet, A. D., Marra, G. E. R., & Braun, H. (2013). Crescimento vegetativo de *Coffea arabica* L. influenciado por irrigação e fatores climáticos no Cerrado Goiano. *Semina: Ciências Agrárias*, *34*(6), 3235-3244. doi: 10.5433/1679-0359.2013v34n6Supl1p3235

International Coffee Organization [ICO]. (2016). *Total production by all exporting countries*. Retrieved on June 28, 2016 from www.ico.org/prices/po-production.pdf.

Jaramillo-Botero, C., Santos, R. H. S., Martinez, H. E. P., Cecon, P. R., & Fardin, M. P. (2010). Production and vegetative growth of coffee trees under fertilization and shade levels. *Scientia Agricola*, *67*(6), 639-645. doi: 10.1590/S0103-90162010000600004

Laviola, B. G., Martinez, H. E. P., Salomão, L. C. C., Cruz, C. D., Mendonça, S. M., & Rosado, L. (2008). Acúmulo em frutos e variação na concentração foliar de NPK em cafeeiro cultivado em quatro altitudes. *Bioscience Journal*, *24*(1), 19-31.

Massarirambi, M. T., Chingwara, V., & Shongwe, V. D. (2009). The effect of irrigation on synchronization of coffee (*Coffea arabica* L.) flowering and berry ripening at Chipinge, Zimbabwe. *Physical Chemistry Earth*, *34*(13-16), 786-789. doi: 10.1016/j.pce.2009.06.013

Nazareno, R. B., Oliveira, C. A. S., Sanzonowicz, C., Sampaio, J. B. R., Silva, J. C. P., & Guerra, A. F. (2003). Crescimento inicial do cafeeiro Rubi em respostas a doses de nitrogênio fósforo e potássio e a regime hídrico. *Pesquisa Agropecuária Brasileira*, *38*(8), 903-910. doi: 10.1590/S0100-204X2003000800002

Ovalle-Rivera, O., Laderach, P., Bunn, C., Obersteiner, M., & Schroth, G. (2015). Projected shifts in *Coffea arabica* suitability among major global producing regions due to climate change. *Plos One*, *10*(4), 1-13. doi: 10.1371/ journal.pone.0124155

Partelli, F. L., Espindola, M. C., Marré, W. B., & Vieira, D. V. (2014). Dry matter and macronutrient accumulation in fruits of Conilon coffee with different ripening cycles. *Revista Brasileira de Ciência do Solo*, *38*(1), 214-222. doi: 10.1590/S0100-06832014000100021

Partelli, F. L., Marré, W. B., Falqueto, A. R., Vieira, H. D., & Cavatti, P. C. (2013). Seasonal vegetative growth in genotypes of *Coffea canephora*, as related to climatic factors. *Journal of Agricultural Science*, *5*(8), 108-116. doi: 10.5539 /jas.v5n8p108

Partelli, F. L., Vieira, H. D., Silva, M. G., & Ramalho, J. C. (2010). Seasonal vegetative growth of different age branches of Conilon coffee tree. *Semina: Ciências Agrárias*, *31*(3), 619-626. doi: 10.5433/1679-0359.2010v31n3p619

Pezzopane, J. R. M., Castro, F. da S., Pezzopane, J. E. M., Bonomo, R., & Saraiva, G. S. (2010). Zoneamento de risco climático para a cultura do café Conilon no Estado do Espírito Santo. *Ciência Agronômica*, *41*(3), 341-348. doi: 10.1590/S1806-66902010000300004

Pezzopane, J. R. M., Pedro Júnior, M. J., Camargo, M. B. P. de, & Fazuoli, L. C. (2008). Exigência térmica do café arábica cv. Mundo Novo no subperíodo florescimento-colheita. *Ciência e Agrotecnologia*, *32*(6), 1781-1786. doi: 10.1590/S1413-70542008000600016

Pinheiro, H. A., DaMatta, F. M., Chaves, A. R. M., Loureiro, M. E., Ducatti, C. (2005). Drought tolerance is associated with rooting depth and stomatal control of water use in clones of *Coffea canephora*. *Annals of Botany, 96*(1), 101-108. doi: 10.1093/aob/mci154

Ramalho, J. C., DaMatta, F. M., Rodrigues, A. P., Scotti-Campos, P., Pais, I., Batista-Santos, P., ... Leitão A. E. (2014). Cold impact and acclimation response of *Coffea* spp. plants. *Theoretical and Experimental Plant Physiology*, *26*(1), 5-18. doi: 10.1007/s40626-014-0001-7

Rodrigues, W. P., Martins, M. Q., Fortunato, A. S., Rodrigues, A. P., Semedo, J. N., Simões-Costa, M. C., ... Ramalho, J. C. (2016). Long-term elevated air [CO_2] strengthens photosynthetic functioning and mitigates the impact of supra-optimal temperatures in tropical *Coffea arabica* and *C. canephora* species. *Global Change Biology*, *22*(1), 415-431. doi: 10.1111/gcb.13088

Sakai, E., Barbosa, E. A. A., Silveira, J. M. C., & Pires, R. C. de M. (2015). Coffee productivity and root systems in cultivation schemes with different population arrangements and with and without drip irrigation. *Agricultural Water Management*, *148,* 16-23. doi: 10.1016/j.agwat.2014.08.020

Sakai, E., Barbosa, E. A. A., Silveira, J. M. C., & Pires, R. C. de M. (2013). *Coffea arabica* (cv. Catuaí) production and bean size under different population arrangements and soil water availability. *Engenharia Agrícola*, *33*(1), 145-156. doi: 10.1590/S0100-69162013000100015

Scotti-Campos, P., Pais, I. P., Partelli, F. L., Batista-Santos, P., & Ramalho, J. C. (2014). Phospholipids profile in chloroplasts of *Coffea* spp. genotypes differing in cold acclimation ability. *Journal of Plant Physiology*, *171*(3-4), 243-249. doi: 10.1016/j.jplph. 2013.07.007

Silva, F. A. S. (2015). *ASSISTAT - Statistical Assistance versão 7.7 beta* [Software]. Campina Grande:

Universidade Federal de Campina Grande. Retrieved on Dez 13 2015 from www.assistat.com /indexi.html.

Silva, P. E. M., Cavatte, P. C., Morais, L. E., Medina, E. F., & DaMatta, F. M. (2013). The functional divergence of biomass partitioning, carbon gain and water use in *Coffea canephora* in response to the water supply: implications for breeding aimed at improving drought tolerance. *Environmental and Experimental Botany*, *87*(1), 49-57. doi: 10.1016/j.envexpbot.2012. 09.005

Soares, A. R., Mantovani, E. C., Rena, A. B., & Soares, A. A. (2005). Irrigação e fisiologia da floração em cafeeiros adultos na região da zona da mata de Minas Gerais. *Acta Scientiarum. Agronomy*, *27*(1), 117-125. doi: 10.4025/actasci agron.v27i1.2128

Vara Prasad, P. V., Allen Júnior, L. H., & Boote, K. J. (2005). Crop responses to elevated carbon dioxide and interaction with temperature. *Journal of Crop Improvement*, *13*(1), 113-155. doi: 10.1300/J411v13n01_07

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