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MICROCLIMATE AND DEVELOPMENT OF *Coffea canephora* INTERCROPPED WITH *Carica papaya*: MEASURES TO MITIGATE CLIMATE CHANGE

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Abstract

Intercropped systems with Conilon coffee might provide a better environment for coffee production. The aim of this study was to assess the microclimate and development of Conilon coffee intercropped with papaya trees. Papaya was planted with spacing of 3.20 x 2.40 m. The coffee trees were planted after eight months, with spacing of 3.20 x 1.60 m, in-between papaya trees (in the same row). The measurements were taken 0, 40 and 80 cm away from the coffee plants, both in the north and south direction. Concomitantly, an adjoining full sunlight coffee system (not intercropped) was also assessed. The measurements included atmospheric parameters (temperature, irradiance, and relative humidity) and vegetative parameters for the coffee plants (leaf area, relative chlorophyll index, length of plagiotropic branches, length of orthotopic branches and number of nodes) in three periods of the year. The intercropped system of Conilon coffee and papaya trees led to a decrease in both irradiance and temperature, and higher means of relative humidity during daytime in all the periods assessed, which contributes to a better environment for coffee cultivation. The shadow provided by papaya trees in the coffee plants contributed to a higher leaf area but did not affect neither the growth of both plagiotropic and orthotopic branches, nor the number of nodes and the etiolation. The intercropped system of Conilon coffee and papaya trees may be potentially used as a farming system to mitigate climate change.

Keywords: Agroforestry systems. Conilon coffee. Papaya trees. Sustainable farming.

1. Introduction

The Conilon coffee (*Coffea canephora* Pierre ex A. Froehner) is an economically and socially important crop for Brazil and for other countries worldwide. During 2018, the global production of coffee was over 169 million of 60-kg-bags whereas 65.35 of the total was from the *C. canephora* (International Coffee Organization 2019). During this year, Brazil was the leader coffee producer, which accounted for over one third of the global production. A total of 14.36 million of 60-kg-bags of Conilon coffee was produced in Brazil in 2018, comprising nearly one fourth of Brazilian coffee production (National Food Supply Company 2019).

Coffee trees are tropical plants that require specific climate for their development (da Silva et al. 2019; Giles et al. 2019, 2018; Martins et al. 2019). Severe environmental conditions, such as high temperatures and high solar irradiance may affect their physiological development (DaMatta et al. 2016;

Rodrigues et al. 2016). In such conditions, both photoinhibition and photorespiration may occur (Martins et al. 2014), limiting photosynthetic processes and therefore stressing the coffee plants and reducing their productivity (Martins et al. 2017).

Coffee plants can be easily adapted to diverse environmental conditions, including coffee production systems under shades of higher trees. Such systems mitigate the increase of temperature, climate variations and possible wind damages (Blaser et al. 2018; Oliosi et al. 2016; Oliosi et al. 2017), contributing, thus, to a more sustainable agriculture, including soil and climate related aspects (Oliosi et al. 2016; Partelli et al. 2014; Pezzopane et al. 2007).

In the view of coffee production intercropped with higher trees, several trees can be used. Fruit trees, for example, reduce the exposure of coffee plants to climatic risks, promoting a greater biodiversity and improving the physiologic and productive performance of the crop, promoting, thus, a more sustainable agricultural system (Araújo et al. 2015; Oliosi et al. 2016).

Fruit trees is a promising alternative to intercrop with coffee plants. It rises as an option for coffee farmers in the face of constant coffee prices fluctuations and can be an option to supply other economically important food products (Hernandez-Aguilera et al. 2018). Within different fruit trees with appropriate characteristics to be intercropped with coffee, the papaya (*Carica papaya* L.) rises a viable alternative, as it is a short-cycle crop, ranging from 24 to 30 months.

Studies about a farming system of coffee plants intercropped with papaya trees and its potential benefits are scarce in the literature. Therefore, this study hypothesized that an intercropped system of Conilon coffee plants and papaya trees provide a viable alternative to mitigate possible damages from climate changes, more specifically in relation to higher temperatures, without compromise the development of the coffee plants. This study aimed to assess the microclimate and development of Conilon coffee under different levels of shading by papaya trees.

2. Material and Methods

Study sites

The experiment was performed in two coffee systems: i) an intercropped system of Conilon coffee plants (*Coffea canephora* Pierre ex A. Froehner) and papaya trees (*Carica papaya* L) and ii) a full sunlight (not intercropped) Conilon coffee production system. The systems were close to each other, and they were located in Sooretama, Espírito Santo State, Brazil (19º 11' S, 40º 05' W and 59 m above sea level) in a flat site. The region has a tropical climate with a hot and humid summer and a dry winter, according to Köppen classification (Alvares et al. 2013).

In the intercropped system, the papaya trees were planted in rows with a 3.20 x 2.40 m spacing. The coffee plants were planted with 3.20 x 1.60 m spacing, eight months after sowing the papaya trees, in-between papaya trees (in the same row). All rows were oriented 70° northwest. The intercropped system was irrigated by drip irrigation. The measurements started when the papaya trees and Conilon coffee plants were 19 and eight months old, respectively. During this period, the *C. canephora* showed an average height of about 80 cm.

In the consortium system, the microclimate was characterized at 0, 40 and 80 cm away of the intercropped row, whereas the 40 and 80 cm points were assessed both for the northern (N) and southern (S) sides. This led to a total of five different shading levels promoted by the papaya trees in the coffee plants. The Figure 1 illustrates the intercropped system and the points of assessments. The absence of shadow was assessed in the full sunlight Conilon coffee production system. Such scheme led to a total of six treatments, each one indicating a different point: i) T1, located within the intercropped row; ii) T40 N, located 40 cm away from the intercropped row in the north side; iii) T80 N, located 80 cm away from the intercropped row in the north side; iv) T40S, located 40 cm away from the intercropped row in the south side; v) T80S, located 80 cm away from the intercropped row in the south side and vi) Tsun, located in the row of coffee plants in the full sunlight system. The experimental plot consisted of tree plants (replicates).

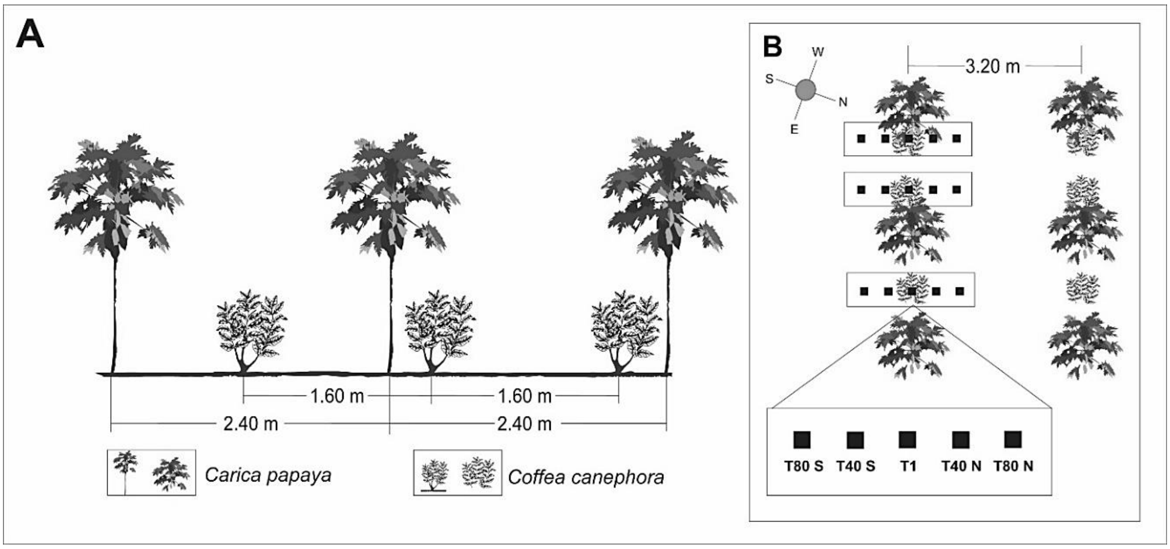

Figure 1. A - Front and B - upper view of the intercropped system of Conilon coffee plants (*Coffea canephora*) and papaya trees (*Carica papaya*) with the assessments points within the system.

Microclimate characterization

The microclimate characteristics evaluated included irradiance, temperature, and relative humidity. The measurements were performed with an external data logger (HOBO U12, Onset HOBO Data Loggers, Bourne, MA, USA), placed 1 m above the soil. Data were recorded at every 10 min. The data were assessed on February 2th (summer), June 15th (autumn) and September 8th (winter) between 05:00 and 19:00 on sunny days. The apparent motion of the sun for the assessment days were 16.76°N (summer), 23.35°S (summer), and 5.26°N (autumn).

Vegetative features

Part of the experimental plot was selected in order to estimate the following coffee plants vegetative features: plant growth, leaf area, chlorophyll a, chlorophyll b, and total chlorophyll content. This included four treatments: i) T40 N, located 40 cm away from the intercropped row in the north side; ii) T40S, located 40 cm away from the intercropped row in the south side; iii) Tsun N, located in north side of the row of coffee plants in the full sunlight system; and iv) Tsun S, located in south side of the row of coffee plants in the full sunlight system.

In order to evaluate coffee plants growth, six plants were assessed in each treatment, with one orthotopic and one plagiotropic branch (of approximately tree nodes) in each coffee plant. The length of the branches was assessed with a measuring tape, along with counting of the number of nodes in each marked branch. The etiolation was calculated as the length of the branch divided by the number of nodes. The individual leaf area was assessed by using the methodology suggested by Partelli et al. (2006).

In order to assess chlorophyll a, chlorophyll b, total chlorophyll content, twenty-five coffee leaves located on the upper portion of the middle third of each coffee plant were assessed in each treatment. Within a plagiotropic branch, the third or fourth pair of leaves were assessed using an electronic chlorophyll content meter (Falker ClorofiLOG® 1030).

Statistical analysis

An analysis of variance (Anova) was performed in the resulting data in order to evaluate the variance between different shadow levels and different assessment periods, both for microclimatic and vegetative parameters. Thereafter, a Tukey test was performed to compare the means ($p<0.05$).

3. Results

Microclimate characterization

Irradiance

Papaya trees reduced the irradiance on coffee trees, only in the months of February and June (Figures 2 and 3). In these months, the lowest irradiance was observed in the evaluations that had the consortium of Carica papaya and Coffea canephora in the same row, and the highest irradiance in the treatments in full sun, without significant difference from the evaluations made 80 centimeters from the intercropped line, regardless of the direction. The irradiance measured 40 centimeters from the intercropped line, on the other hand, presented intermediate values.

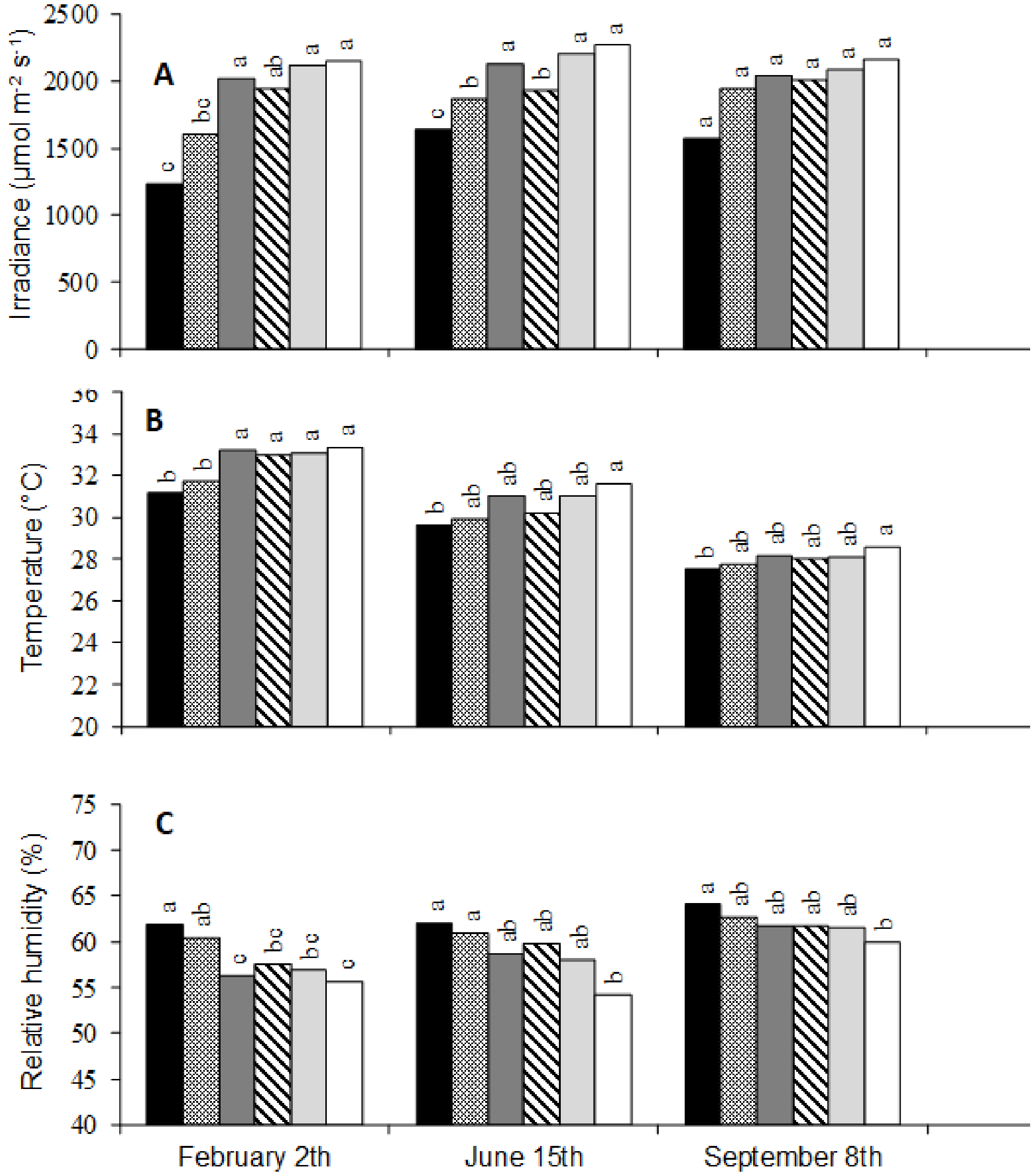

Figure 2. A - Irradiance, B - temperature, and C - relative humidity on February 2th, June 15th and September 8th. T1: intercropped row of *Carica papaya* and *Coffea canephora*. T40N: 40 cm away from the intercropped row in the north side. T80N: 80 cm away from the intercropped row in the north side. T40S: 40 cm away from the intercropped row in the south side. T80S: 80 cm away from the intercropped row in the south side. Tsun: located in the row of coffee plants in the full sunlight system. Means followed by different lowercase letters in the bars differ statistically from each other according to the Tukey test at 1% and 5% probability within each time. CV%: February 2th = 2.14%; June 15th = 3.34% and September 8th = 7.58.

Therefore, the lowest incident irradiance was observed in the consortium of papaya and coffee trees (T1), which intercepted 42% of the incident irradiance of Tsun, the coffee system in full sun (Figure 3A). The remaining treatments (T40N, T40S, T80N and T80S) intercepted 26, 10, 6, and 2% of the Tsun incident irradiance, respectively.

Significant interception was also observed in June in the shadowed plants (Figure 3B), whereas the treatments T1, T40N and T40S intercepted 28, 18 and 15% from the incident irradiance, respectively.

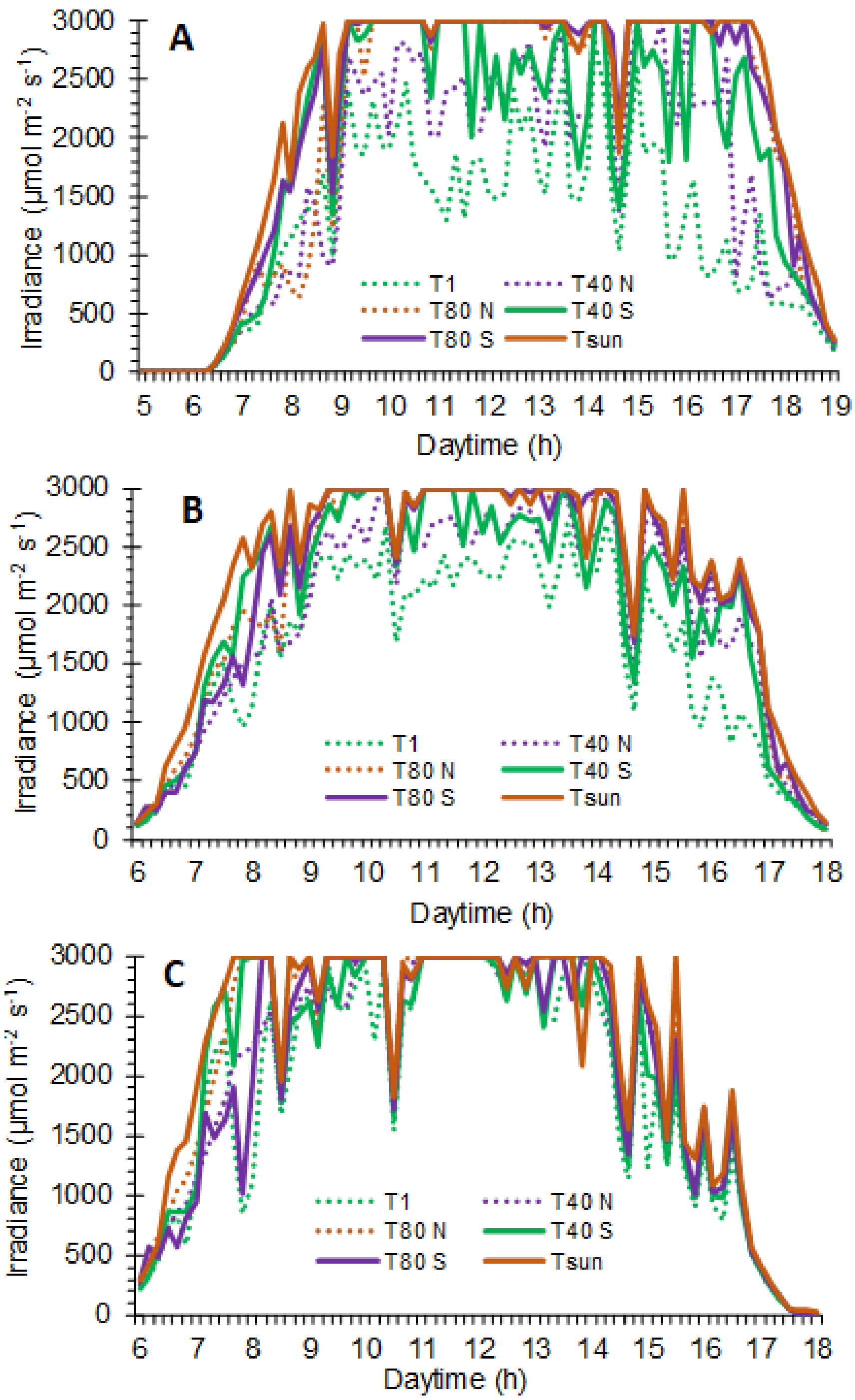

Figure 3. A - Irradiance on February 2th, B - June 15th and C - September 8th. T1: intercropped row of *Carica papaya* and *Coffea canephora*. T40N: 40 cm away from the intercropped row in the north side. T80N: 80 cm away from the intercropped row in the north side. T40S: 40 cm away from the intercropped row in the south side. T80S: 80 cm away from the intercropped row in the south side. Tsun: located in the row of coffee plants in the full sunlight system.

Temperature

The mean daytime temperature was lower in the intercropped row of Carica papaya and Coffea canephora only in relation to the evaluation of the treatment in full sun, in the months of June and September. However, in the month of February, the temperature measured at 40 centimeters from the intercropped row (north direction) also showed lower values in relation to the other treatments (Figure 2B and Figure 4). During summer, for example, there were reductions of 2.2 and 1.6 °C in the intercropped rows of papaya trees and Conilon coffee (T1) and in the distance of 40 cm away from the intercropped row, respectively, in relation to Tsun, the full sunlight coffee production system (Figure 2B). During the warmer period (at 12h), the temperature in the shadowed coffee plants was decrease up to 8.3 °C.

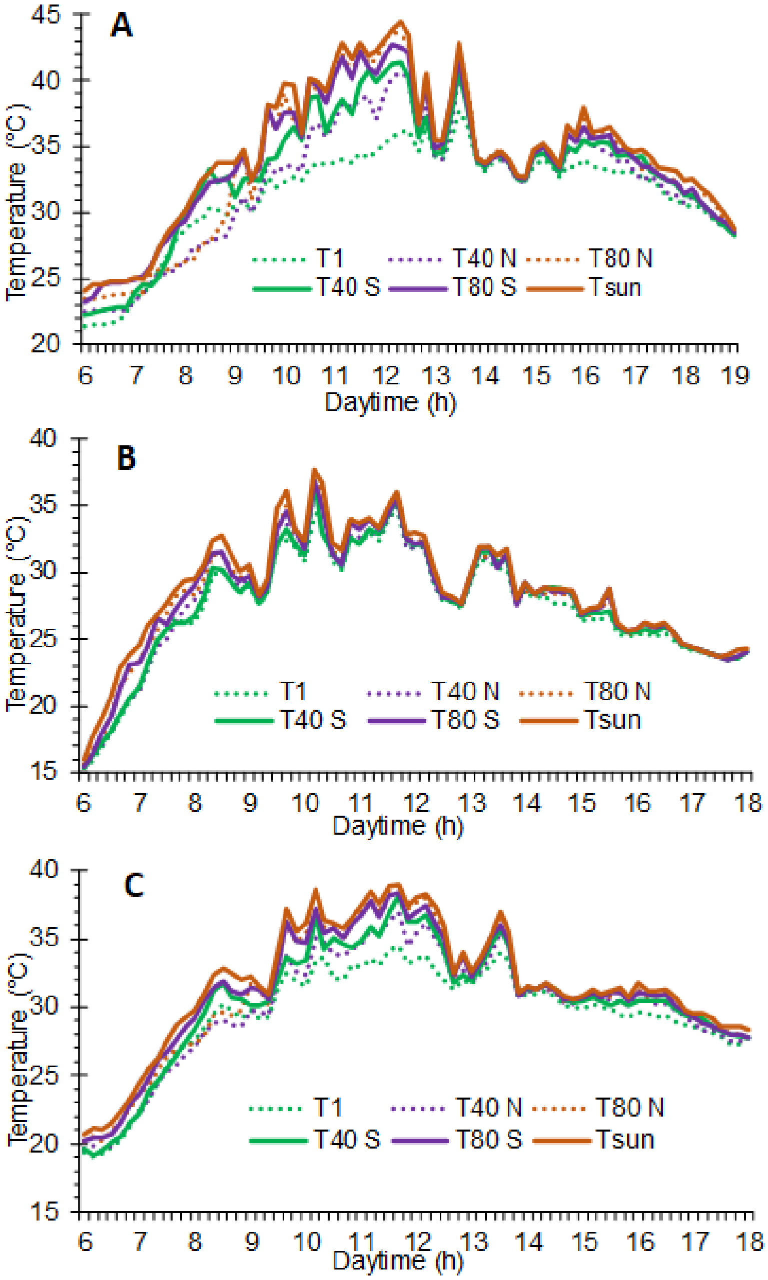

Figure 4. A - Irradiance on February 2th, B - June 15th and C - September 8th. T1: intercropped row of *Carica papaya* and *Coffea canephora*. T40N: 40 cm away from the intercropped row in the north side. T80N: 80 cm away from the intercropped row in the north side. T40S: 40 cm away from the intercropped row in the south side. T80S: 80 cm away from the intercropped row in the south side. Tsun: located in the row of coffee plants in the full sunlight system.

During daytime (Figure 4B), the average temperature decrease was up to 4.4 °C for the shadowed coffee plants. In September (Figure 3B), the period of mild temperatures, there was a reduction of 1.07 °C for the average temperature in T1 and 0.85, 0.43, 0.54 and 0.50 for the T40N, T80N, T40S and T80S, respectively.

Relative air humidity

The relative humidity in the intercropped system was higher than the full sunlight coffee production for all assessments periods. The relative humidity was higher in the early mornings (period of lower temperatures) and lower after noon (period of higher temperature), increasing again late in the afternoon (Figure 2C and 5).

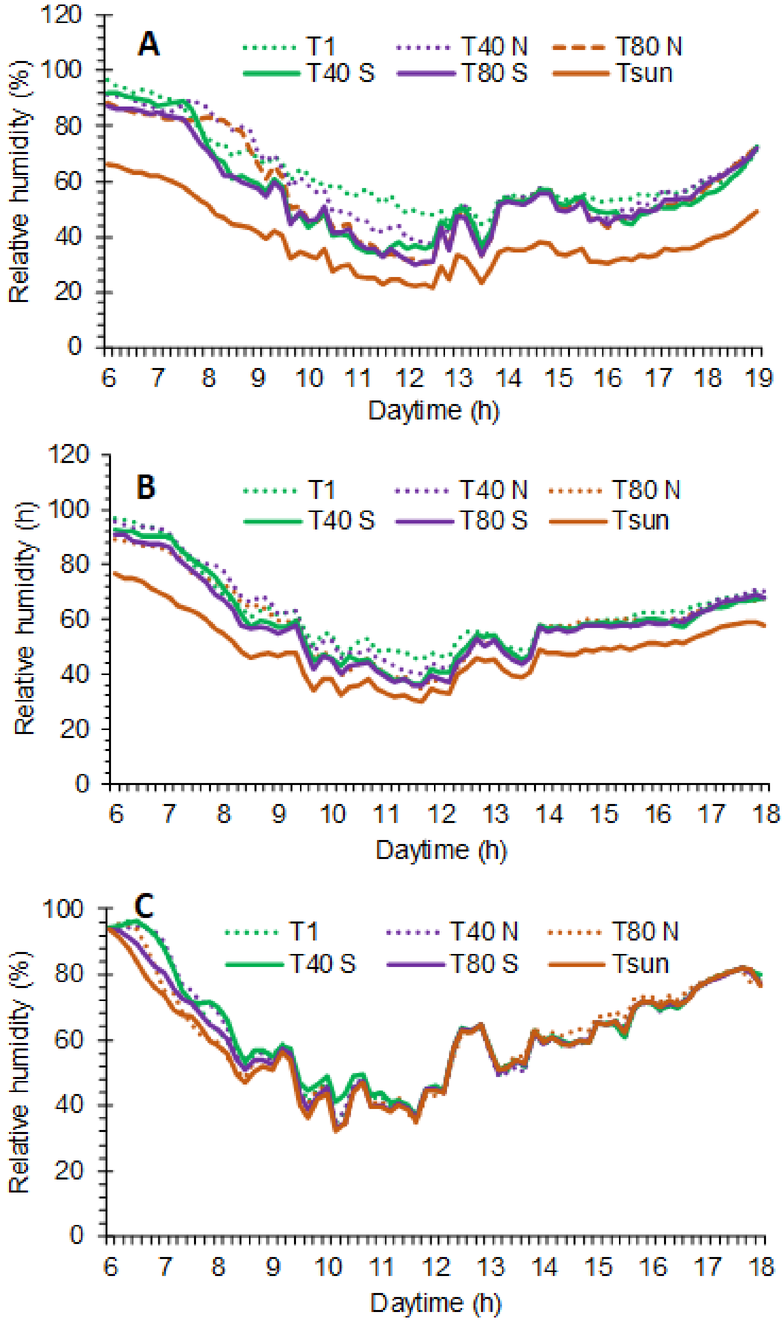

Figure 5. A - Irradiance on February 2th, B - June 15th and C - September 8th. T1: intercropped row of *Carica papaya* and *Coffea canephora*. T40N: 40 cm away from the intercropped row in the north side. T80N: 80 cm away from the intercropped row in the north side. T40S: 40 cm away from the intercropped row in the south side. T80S: 80 cm away from the intercropped row in the south side. Tsun: located in the row of coffee plants in the full sunlight system.

The highest recorded relative humidity was during winter, at 06:20h in the morning, with 96.31% in the treatment T1, whereas the Tsun recorded, at the same time, 88.05%, indicating a difference of 8.26%.

Moreover, the higher difference was recorded during February, at 06:40h in the morning, where the relative humidity in treatment T1 and Tsun were 92.95% and 63.52%, with a difference of 29.43%.

Vegetative characteristics

The intercropped system of *C. canephora* and *C. papaya* (T1) did not negatively affect the growth of the coffee plants. Chlorophyll a, b and total chlorophyll did not vary significantly between evaluations at full sun and those performed at 40 centimeters from the intercropped lines in the summer and autumn period. However, in the winter, differences were noted, with emphasis on total chlorophyll in the treatment in full sun, in the north direction that presented the highest total chlorophyll content (Table 1).

In general, shading promoted an increase in the leaf area in coffee plants during all the evaluation periods, with the lowest averages for the coffee production system in full sun on the north side (Tsun N) (Table 1).

Table 1. Leaf area and chlorophyll content in coffee plants in an intercropped system (T40) and in a full sunlight production system (Tsun), both in the north and south side, assessed during summer, autumn and winter.

	Leaf Area (cm²)			Chlorophyll a (FCI)			Chlorophyll b (FCI)			Total Chlorophyll (FCI)		
Treatment	Summer	Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter	Summer	Autumn	Winter
Tsun S	43.0^{a}	42.8^{ab}	26.3^{ab}	41.9^{a}	41.0^{a}	25.8^{b}	23.9^{a}	28.7^{a}	16.0^{b}	65.8^{a}	69.8^{a}	41.8^{b}
Tsun N	36.5^{b}	38.1^{b}	28.7^{ab}	42.4^{a}	39.7^{a}	35.0^{a}	24.8^{a}	25.0^{a}	22.2^{a}	67.2^{a}	64.9^{a}	57.2^{a}
T40 S	47.0^{a}	43.5^{ab}	24.1^{b}	42.5^{a}	40.4^{a}	30.0^{ab}	26.6^{a}	26.6^{a}	12.9^{b}	69.2^{a}	67.0^{a}	42.9^{b}
T40 N	48.3^{a}	46.1^{a}	30.9^{a}	41.6^{a}	40.6^{a}	23.7^{b}	24.6^{a}	26.2^{a}	12.1^{b}	66.3^{a}	66.8^{a}	35.8b
CV (%)	20.05	20.85	28.84	3.88	4.86	38.26	15.52	19.78	45.89	7.97	10.49	37.90

Means followed by the same letter within each column do not differ from each other according to the Tukey test ($p<0.05$). TsunN: the north side of the row of coffee plants in the full sunlight system. TsunS: the south side of the row of coffee plants in the full sunlight system. T40N: 40 cm away from the intercropped row of *Carica papaya* and *Coffea canephora* in the north side. T40S: 40 cm away from the intercropped row in the south side.

4. Discussion

Microclimate characterization

Irradiance

As the global coffee production and its sustainability has been potentially threated by constant climate changes (DaMatta et al. 2012), some coffee species has been described as highly sensible to such changes (Craparo et al*.* 2015). Considering the origin and evolution of coffee plants in shadowed environments, it is believed that high irradiance levels may impair the development of coffee plants (DaMatta, 2018). In this study, the variations in the irradiance values were due to the distance of the coffee plants in relation to the papaya trees in the positions north-south and also in relation to daytime. Furthermore, small variations took effect throughout the day due to the solar position and its declination.

The production of coffee systems under shades has been studied as a promising alternative to mitigate the damages from climate changes (Pezzopane et al. 2011; Partelli et al. 2014; Araújo et al. 2015; Araújo et al. 2016; Oliosi et al. 2016). This study, which assessed the *C. canephora* intercropped with *C. papaya*, confirm the efficiency of coffee systems under shades alternative to mitigate the damages from climate changes, as the treatments T1, T40N and T40S promoted reduction in the incident irradiance in the plants.

The irradiance reduction of 42% in the T1 treatment in relation to the full sunlight coffee system was provided by the shadowing, which did not impair the development of the coffee plants in the environmental conditions of this study. Similarly, in coffee production systems intercropped with *Musa spp*. AAB from Pezzopane et al. (2007) and with green dwarf coconut trees from Pezzopane et al. (2011) reduced up to 27% of the irradiance and did not influence the growth and development of coffee plants.

Intercropped coffee production systems were also studied in relation to the intercropping with *Hevea brasiliensis*. Partelli et al. (2014) have also verified a decrease in the irradiance, mainly in the coffee plants close to the rubber trees, where a considerable part of the irradiance was retained by the tree canopy, promoting, thus, changes in the microclimate conditions near the coffee plants.

A work conducted by Araújo et al. (2016) studied the intercropped system of Conilon coffee and *H. brasiliensis*. They observed a decrease of 88 and 72% in the light transmittance during summer and winter, respectively. Differently from this study, the authors mentioned that such level of shadowing promoted physiologic changes in the coffee plants, including etiolation and an increase in the leaf area in the shadowed coffee.

Temperature

Similar to irradiance, the reduction in temperature in the intercropped system was due to shadowing promoted by papaya trees. High temperatures may cause several changes in metabolic processes, such as protein denaturation, stomatal closure and increased production of reactive oxygen species (Rodrigues et al. 2016; Martins et al. 2017). Moreover, high temperature may cause abnormal flower development or even full inhibition of flowering (DaMatta et al. 2012), promoting an expressive reduction in the growth rate, which negatively impacts the productivity of coffee grains (Partelli et al. 2013; Covre et al. 2016).

The ideal average annual temperature for *C. canephora* development ranges from 22 to 26 °C (DaMatta and Ramalho, 2006). The increase of temperature due to global warming might threat the production and thereafter the supply of *C. canephora* in the near future (Bunn et al. 2015; Davis et al. 2012). In this context, adaptation and mitigation strategies needs to be used in order to improve *C. canephora* production systems and therefore promotes its sustainability.

The intercropped system used in this studied was efficient to minimize the temperature around the coffee plants, as it reduced 2.2 °C in the average temperature and up to 8.3 °C in the average daytime temperature in February (Figure 3B). Fruiting takes place in this period, with low vegetative growth (Partelli et al. 2010; Partelli et al. 2013; Covre et al. 2016). Thus, such reduction in the average temperature is beneficial, as it contributes to a better development of coffee plants. Moreover, this is significant because such coffee production systems may be used in the future, in environments with higher temperatures.

In a coffee production system intercropped with *Musa spp.*, Araújo et al. (2015) noted a temperature decrease from 3 to 4 °C during summer and 1.9 % during winter. Partelli et al. (2014) in a similar study, verified a temperature reduction up to 6.2°C in coffee plants intercropped with *H. brasiliensis*. Besides the potential benefits clearly found by the authors, they did not find morphophysiological changes in the coffee plants and similarly to this study, they noted mild microclimatic conditions, mainly by the reduction of irradiance and decrease in the leaf's temperature.

Relative air humidity

The effects of shadowed *C. canephora* decreasing both irradiance and temperature and increasing relative humidity from 5 to 7% has been previously reported in the literature (Pezzopane et al. 2010; Partelli et al. 2014; Oliosi et al. 2016). In this study, the increase of relative humidity (by 29.43%) was higher than the previous reported by the above-mentioned authors. Such increase, along with the decreased temperature and low wind speed, may be beneficial for the coffee plants, reducing the water vapor deficit between leaves and atmosphere, decreasing water loss from the plants transpiration and favoring leaf expansion (Otoni et al. 2012).

Vegetative characteristics

Intercropped systems for coffee production generally promote changes in the microclimate and according to coffee plants plasticity, it can affect their anatomy and physiology (Morais et al. 2004). The extend of such effect depend upon some factors, including the type of the intercropped system, the density of the intercropped specie, its genotype, age, the level of shadowing and the climatic conditions (Morais et al. 2008; Morais et al. 2009). In this study, the intercropped system of *C. canephora* and *C. papaya* did not negatively affect the growth of the coffee plants and it promoted a mild microclimate, which evince its suitability to mitigate future climate changes.

Similar results for chlorophyll b and total chlorophyll were previously found by Partelli et al. (2014) during winter in coffee plants intercropped with rubber trees and by Gonçalves et al. (2007) for chlorophyll b in leaves in a less shadowed coffee production system. According to Feng et al. (2004) the developed leaves in shadowed environments generally have high total chlorophyll content per unit of weight, increasing, thus, the capability of irradiance absorbance. In this study, the irradiance was similar to all treatments during winter, (Figure 2), indicating low shadowing in the coffee plants close to papaya trees. According to Okada et al. (1992), the irradiance may reduce the chlorophyll and protein decay. The chlorophylls are rapidly degraded in the leaves under total darkness. However, their decomposition is markedly delayed when there is incident of a weak white light.

In an intercropped system of coffee production, distinguished changes in the morphological characteristics of coffee plants may happen throughout the year, such as increased growth of both plagiotropic and orthotropic branches, increased number of nodes per branch and larger distance between internodes (Ricci et al. 2011; Ricci et al. 2013; Oliosi et al. 2016).

The differences for lead area between seasons, as well as different orientated sides (north and south) from the coffee plants might be related with solar inclination and/or irradiance. The sun path and the irradiance level significantly influences the coffee production system, as shadowed plants generally increase leaf area due to lower intensity of the received photon flux (Valladares et al. 2006). The leaf expansion is a typical process in shadowed coffee plants (Partelli et al. 2014), used to balance the lower incident irradiance. Therefore, it is an acclimatization strategy of the coffee plants to collect the maximum radiation possible in order to fulfil its metabolic requirements (Ricci et al. 2011). Moreover, the leaves directly exposed to the sunlight are generally smaller due to its cells arrangement in the mesophyll, which increase the surface in contact with air, enabling a more efficient latent heat loss and effective leaf cooling (Rubio De Casas et al. 2007).

5. Conclusions

The intercropped system of *C. canephora* and *C. papaya* assessed during the growth stage of the coffee plants (up to 26 months old) promoted a decrease in irradiance and temperature and an increase in relative air humidity during daytime, promoting a better suited environment for coffee production. The intercropped system promoted higher leaf expansion in relation to the full sunlight coffee system, indicating the adaptability of coffee plants in environments with lower incident irradiance.

The intercropped system was thereafter efficient to promote a better environment for coffee production, indicating that such system has a great potential to mitigate climate change, as it did not negatively affect the coffee plants development, enabling a more sustainable system for coffee production, contributing for coffee farmers as well for the environment.

Authors' Contributions: TREVISAN, E.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article; OLIVEIRA, M.G.: acquisition of data, analysis and interpretation of data; VALANI, G.P.: acquisition of data, analysis and interpretation of data; OLIOSI, G.: acquisition of data, analysis and interpretation of data; ZUCOLOTO, M.: acquisition of data, analysis and interpretation of data; BONOMO, R.: acquisition of data, analysis and interpretation of data; PARTELLI, F.P.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

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