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Microclimate and development of *Coffea canephora* cv. Conilon under different shading levels promoted by Australian cedar (*Toona ciliata* M. Roem. var. Australis)

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Abstract

Coffee growers are searching for more sustainable production systems. Shaded cultivation is presented as a management option to attenuate coffee environmental stresses. This work aims at to evaluate the microclimate and coffee plant (*Coffea canephora* cv. Conilon Clone 02) development under different shading levels promoted by the intercropping with Australian cedar (*Toona ciliata* M. Roem. var. Australis) or under unshaded conditions. Australian cedar and Conilon coffee were planted in 15 × 2m and 3 x 1.2 m spacing, respectively, resulting in five rows of coffee to one row of Australian cedar. The closer the coffee rows were in relation to the Australian cedar trees the higher shade level was obtained. Climatic variables (temperature, irradiance and relative humidity) and leaf areas were evaluated over four seasons, and the internode lengths of plagiotropic and orthotropic branches were evaluated monthly. The 2013yield was also measured. There was a decrease in both the irradiance and temperature and an increase in the relative humidity at all times under shaded cultivation (closer to the Australian cedar row). The highest growth of plagiotropic and orthotropic branches and leaf expansion were found under shaded cultivation; however, the number of nodes per branch and the yields were similar among treatments. Growing Conilon coffee intercropped with Australian cedar showed a good yield potential.

Keywords: Agroforestry systems; *Coffea canephora*; Intercrop; *Toona ciliata*.

Introduction

The *Coffea* genus includes at least 124 species (Davis et al., 2011), among which *Coffea arabica* L. and *C. canephora* Pierre ex A. Froehner are the most important in economic terms. Brazil is the largest producer and exporter of coffee (ICO, 2015), but with a huge social-economic importance of this crop in the tropical area. The Australian cedar (*Toona ciliata* M. Roem.) belongs to the Meliaceae family, naturally occurring from India and Malaysia to northern Australia (Lorenzi et al., 2003). Australian cedar exhibits rapid growth and high-quality wood and can be used together with coffee to diversify production, distributing the economic return over the year and providing a better utilization of the area (Müller et al., 2004). Coffee is often subjected to supra optimal temperatures that sometimes exceed 38 ºC during the critical grain filling phase (Partelli et al., 2010; 2013; 2014b). These conditions, coupled with the occurrence of strong winds and high rates of evapotranspiration, can be stressful to the crop, requiring different management techniques to mitigate these problems (Partelli et al., 2014a). In addition, temperatures above 35 °C, particularly if associated with a prolonged dry season, will increase the probability of sterile flower formation (Camargo and Camargo, 2001) and increase flower abortion (Camargo, 2010) and flower burning before anthesis, affecting as well the germination and pollen tube growth and consequently ovary fertilization, reducing fruit production (Custódio et al., 2014). Finally, high temperatures during bean development are usually related to a loss of quality and impact at beverage level (Santos et al., 2015). Mitigation of climate constraints could be promoted by coffee shaded cultivation (Pezzopane et al., 2010; Pezzopane et al., 2011; Partelli et al., 2014a). In fact, it was reported that coffee plants grown under shaded systems greater physiological potential for carbon gain, and better photosynthetic performance than those grown exposed to full sunlight, producing larger grains with improved organoleptic quality of the grains. Furthermore, lower climate variables pressure was found under shaded cultivation, and lower incidence of *Cercospora coffeicola* (Bote and Struik, 2011; Steiman et al., 2011; Baliza et al., 2012). Australian cedar trees could contribute to the greater protection of coffee plants against cold winds, frost, high temperatures and excessive irradiance (Morais et al., 2007; Pezzopane et al., 2010). Furthermore, shaded systems can be a valuable tool for mitigating the effects of climate changes (Camargo, 2010) predicted by the Intergovernmental Panel on Climate Change, or IPCC (IPCC, 2014). Therefore, intercropping coffee in order to generate moderate shading systems improves environmental sustainability, increases the stability of crop production by mitigating potentially stressful conditions, and allows the farmers to obtain other economic important products (DaMatta et al., 2007).

The objective of this study was to evaluate the microclimate and development of Conilon coffee that was subjected to different shading levels by Australian cedar trees along the year in order the clarify the potential usefulness of this intercropping approach.

Results and Discussion

Microclimate characterization

Australian cedar trees promoted a reduction of the irradiance incidence at coffee leaf level. The full sun exposed coffee plants showed higher average irradiance values at all year periods, both with southern and northern orientation in relation to the Australian cedar row. However, the observed irradiance exposure depended on the distance to the Australian cedar row, the northern or southern position of the row, and the time of day or year (Fig. 1 and 2). These results corroborate those obtained by Partelli et al. (2014a) on Conilon coffee shaded by rubber trees (*Hevea brasiliensis*).

On winter time (Fig. 1A), there were lower irradiance values for the coffee rows located on the southern side (both on T1 and T2 distances), with average intercepts of 49% and 46%, respectively, for incident irradiance. The northern treatments presented interceptions of 38% (T1) and 35% (T2). That was mostly related to the lower irradiance values reaching the plants in the morning, due to irradiance interception by the cedar trees, although some differences were present also along the rest of the day. In the spring (Fig. 1B), the T1 southern, T2 southern, T1 northern and T2 northern treatments showed average irradiance intercepts of 51%, 29%, 40% and 52%, respectively. These resulted from the variations in irradiance values throughout the day under different distances to the cedar trees, with the coffee row located close to Australian cedar on the southern side (T1 southern) showing lower irradiance values at certain times of the day. During the summer (Fig. 1C), the lowest irradiance incidence was foundT1 northern, but all treatments presented significant lower irradiance levels in comparison to T3. The interception average ranged between70% (T1 northern) and 46% (T2 northern).Considering the daily irradiance during the summer (Fig. 2C), there were lower values throughout the day for the coffee row located close to the Australian cedar on the T1 northern. The coffee rows that were located 4.5 m from the Australian cedar (T2) on the northern side showed high irradiance values in the morning, similar to those observed on the unshaded coffee rows (T3 unshaded). However, in the mid of the day and partly on the afternoon those values strongly decreased on T2 in comparison to T3. The coffeeT1 and T2 treatments on the southern side showed lower values in the morning, reaching similar levels to those located in unshaded rows (T3 unshaded) in the late afternoon. This observed variation throughout the day under different shading levels is a function of the sun position. Martins et al. (2013) observed that shaded coffee leaves showed an overinvestment in photosynthetic machinery, enabling the coffee to cope with rapid exposure to high irradiance under shaded conditions. During the autumn (Fig. 1D), there lower irradiance values were found on both T1 and T2 of the southern side, with average interceptions of the incident irradiance of 63% and 61%, respectively. The T1 and T2 treatments on the northern side presented interceptions of 41% and 31%, respectively. With respect to the daily irradiance (Fig. 2D), the lowest values occurred during the early hours of the day under Australian cedar trees, quite similar to what was observed for winter conditions (Fig.1A and 2A).

Conilon coffee shaded systems with macadamia (*Macadamia integrifolia*) and coconut (*Cocus nucifera* L), presented as well as reduced lower radiation levels on the rows close to the shading trees, which promoted strong irradiance interception and caused changes in the environment microclimate conditions (Pezzopane et al., 2010; 2011). Furthermore, *C. arabica* and shading promoted by *Inga densiflora* in Costa Rica (Siles et al., 2010) showed greater coffee fruit quality and plant biomass up to threefold compared with a monoculture. On the other hand, a radiation interception of 50% on shaded *C. arabica* did not caused changes in the growth, maturation, production and grain size (Morais et al., 2009). The photosynthetic light saturation is generally *ca*. 600 µmol m^{-2} s^{-1} for sun-grown and *ca*. 300 µmol $m^{-2}s^{-1}$forshade-grown coffee (Kumar and Tieszen, 1980; Fahl et al., 1994; Martins et al., 2014). Therefore, the average intercept of 47% observed in this work is within the range proposed by those authors. Studies on arabica coffee grown under agroforestry systems have shown limitations for both stomatal conductance and light availability for coffee photosynthesis under shade levels above 45% (Franck and Vaast, 2009). Carelli et al. (1999) observed significant reductions in photosynthesis and stomatal conductance with light interception of 80%; however, they found no differences in these variables with a light interception of 50%. On the other hand, Ronquim et al. (2006) reported that arabica coffee leaves experience up to threefold increase in their daily net photosynthesis under *ca*. 800-1,100 µmol m^{-2} s^{-1}irradiance and *ca*. 0.5-2.5 kPa vapour pressure. Shading by Australian cedar trees promoted a reduction in the average daily temperature for all periods. In fact, full sun exposed coffee plants (T3 unshaded) showed the highest temperature values, although the difference changed with T1 and T2 treatments (distance to shading tree), with southern/northern orientation and along the year (Fig. 3 and 4), what would be closely related to the irradiance at leaf level (Fig. 1). On winter season, a reduction of 0.7 °C of the average daily temperature was observed on both distances (T1 and T2) of the southern side, when compared to T3 plants (Fig. 3A). For northern orientation the average reduction reached 0.2 (T1) and 0.4 °C (T2), significantly only for the latter. These average differences will mostly related to the lower temperature values in the early morning, since afterwards the temperatures tended to be similar among treatments throughout the day (Fig. 4A). During spring (Fig. 3B) the daily average temperatures showed the minimal differences amongst all treatments for the entire year. Although with some statistical differences, the differences to T3 plants ranged only from 0.1 ºC (T1 northern) to 0.4 ºC (T1-southern), what agrees with the large overlapping of daily temperature patterns (Fig. 4B). The quite modest differences between T3 and all the other shaded treatments on both winter and spring would be associated with the lower leaf area index of Australian cedar, since it is a deciduous tree (Lorenzi et al., 2003). During summer season (Fig. 3C), the temperature differences between T3 and the shaded treatments, mainly in the T1 plants (closer to the Australian cedar), were enlarged. T1 northern and T1 southern showed mean daily temperatures reductions of 3.5 and 2.8 °C, respectively, whereas T2 southern and T2 northern values decreased 1.3 and 1.0 °C, respectively. These differences were related to lower temperature values observed in the

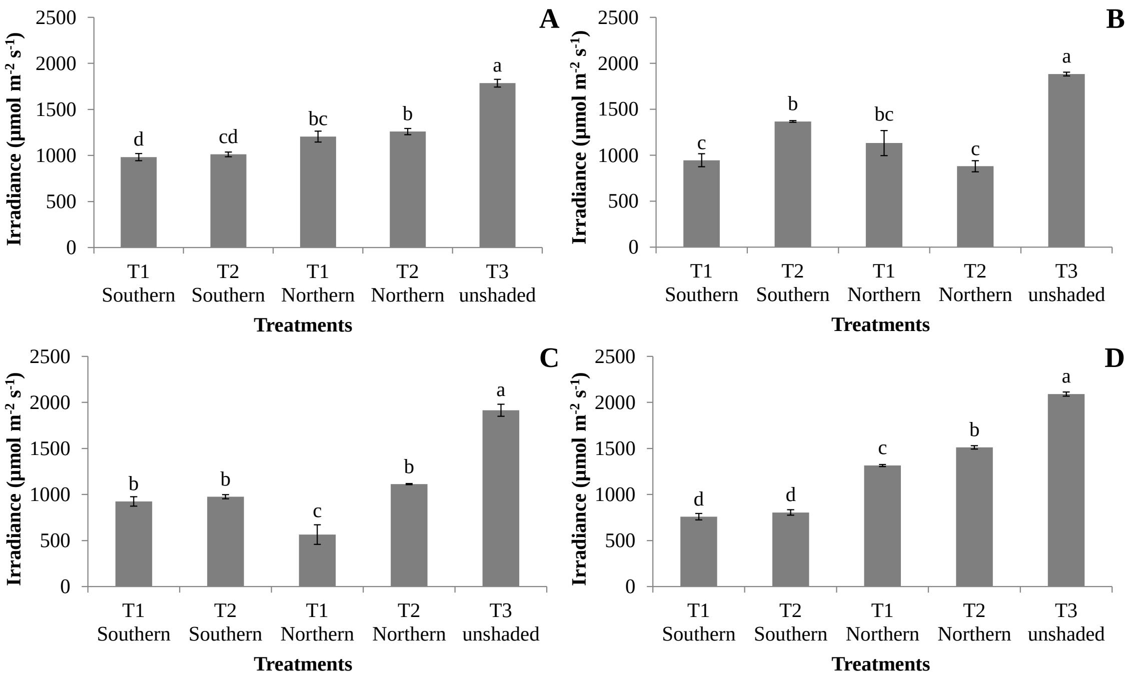

Fig 1. Average daily irradiance during the winter (A), spring (B), summer (C) and autumn (D) on conilon coffee that was grown in the shade under Australian cedar in which the coffee row was located 1.5 m from Australian cedar on the southern side (T1 southern) or on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded). Vertical bars represent the standard error of mean. Bars followed by the same letter do not differ by Tukey's test at 5 %. CV%: winter = 5.84%; spring = 9.69%; summer = 9.72%; and autumn = 3.30%.

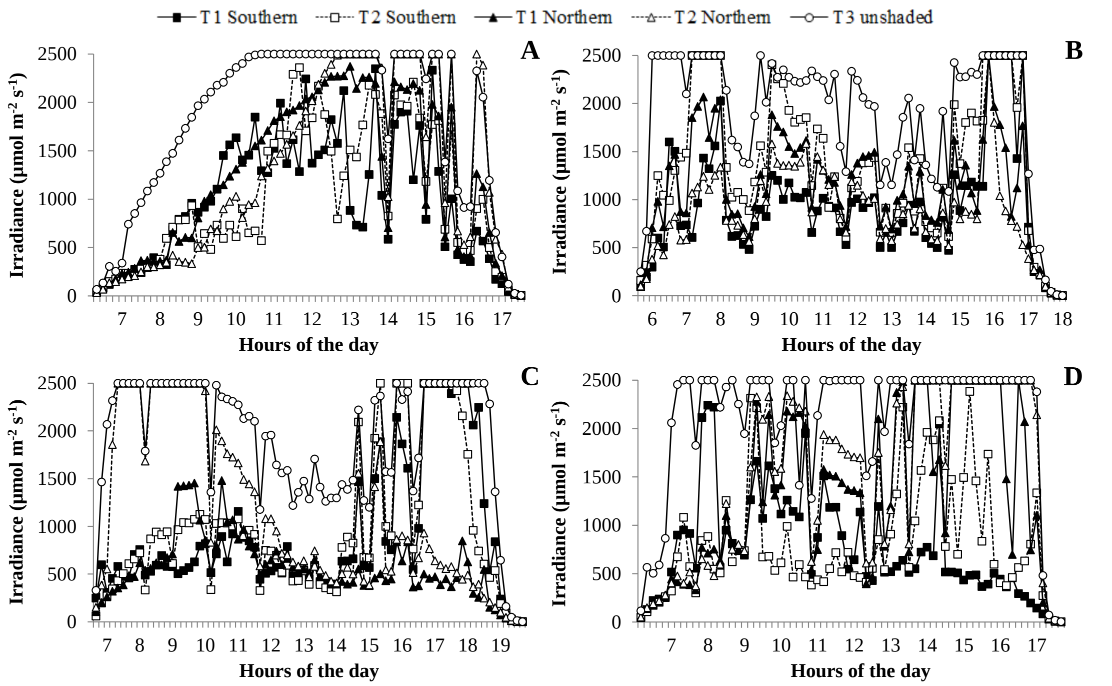

Fig 2. Average daily irradiance values during the winter (A), spring (B), summer (C) and autumn (D) in conilon coffee shaded by Australian cedar for a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded).

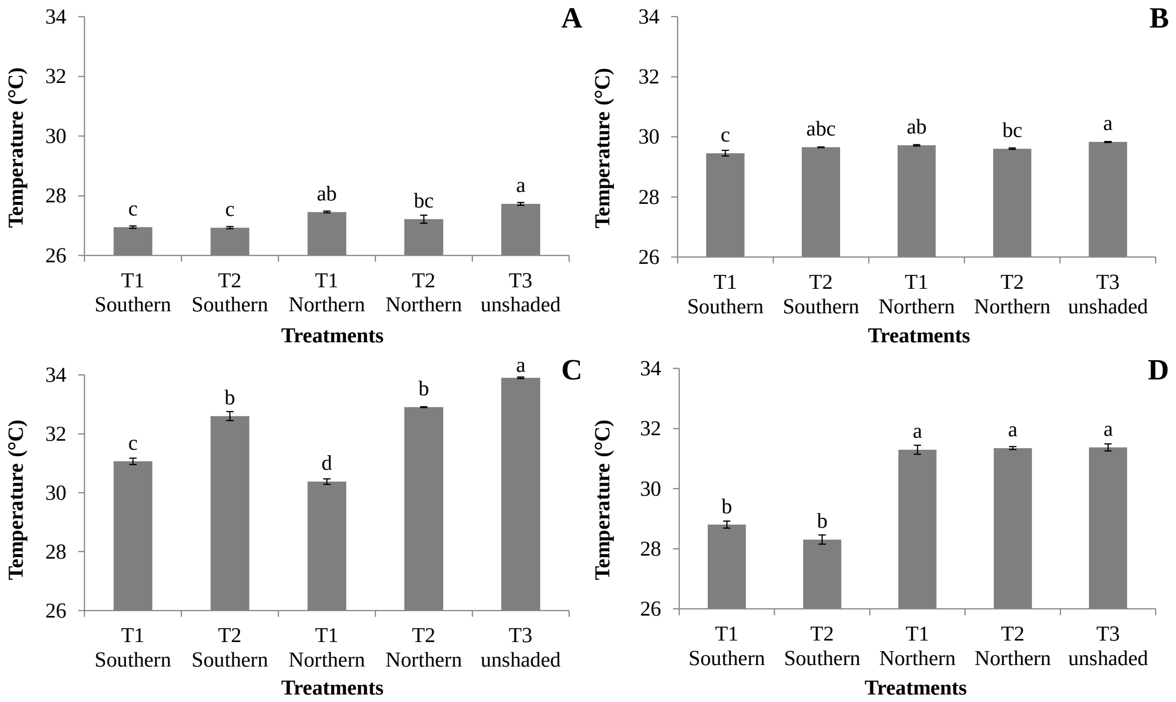

Fig 3. Average daily temperature during the winter (A), spring (B), summer (C) and autumn (D) on conilon coffee that was grown in the shade provided by Australian cedar, with a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded). Vertical bars represent the standard error of mean. Bars followed by the same letter do not differ by Tukey's test at 5 %. CV%: winter = 0.44%; spring = 0.26%; summer = 0.49%; and autumn = 0.73%.

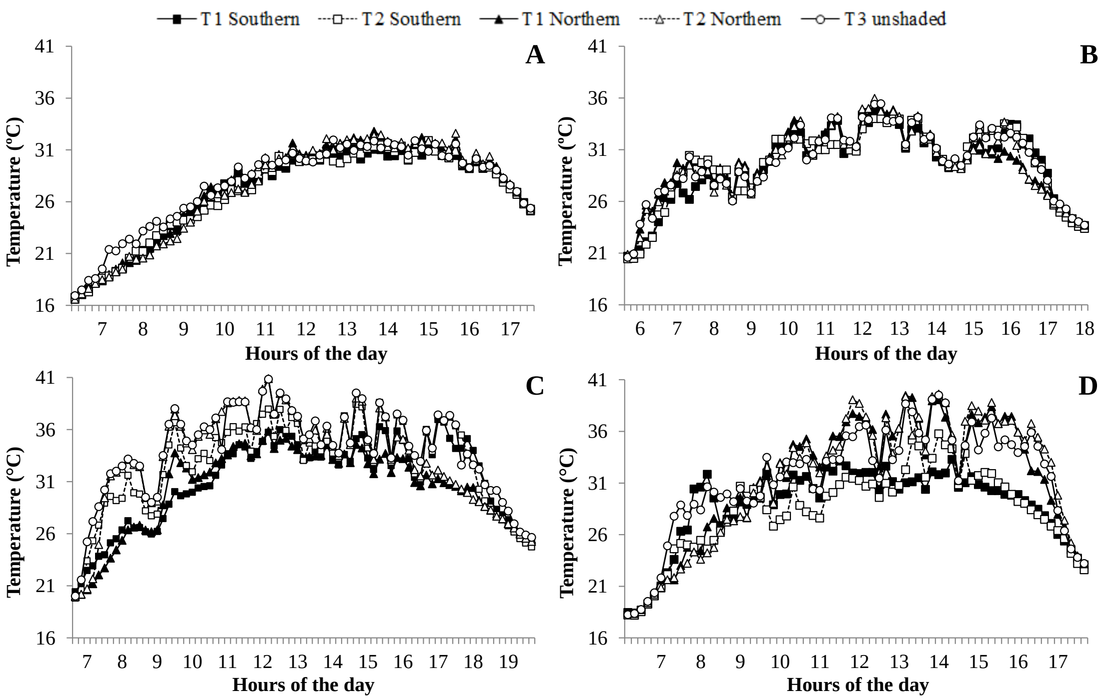

Fig 4. Average daily temperatures in the winter (A), spring (B), summer (C) and autumn (D) on conilon coffee grown in the shade under Australian cedar, with a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern)and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded).

rows closest to the Australian cedar (T1 northern and T1 southern) in the morning, and also in the northern side (T1 and T2) in the late afternoon (Fig. 4C). This behavioural variation occurs because of the sun's position in relation to the Australian cedar rows. Finally, for autumn measurements (Fig. 3D), lower mean daily temperatures were observed only on the southern side, for bothT1 and T2, with an average reduction of 2.6 and 3.1 °C, respectively, to T3 treatment. That was related to the lower temperature values found for most of the day in T1 and T2 southern treatments (Fig. 4D).

This data are in agreement with the reports that Conilon coffee plants presented temperature decreases up to 6.2 °C close shading rubber trees (Partelli et al., 2014a), or reductions in air temperature range and leaf and soil temperatures when shaded with Gliricídia (*Gliricidia sepium*) and Erythrina (*Erythrina poeppigiana*) (Ricci et al., 2013), resulting in better environmental temperature conditions to the coffee plant. One of the largest reductions in temperature were observed during the summer (T1 treatments), when coffee fruiting and higher vegetative growth rates occurred (Partelli et al., 2010; 2013). Therefore, the exposure to average daily temperature reductions of up to 3.5 °C (Fig. 3C) might contribute to mitigate the high temperature effects on the coffee. By this season, supra optimal temperatures of up to 41 °C were observed (ca 12:10 am) (Fig. 4C), what can disturb to plant metabolic processes and promote leaf damages (DaMatta and Ramalho, 2006).

According to Bunn et al (2015), higher temperatures may imply reduction in area suitable for coffee production. However, Rodrigues et al. (2016) evaluating the interaction of high temperature coupled with the increase of CO_2 concentration on *Coffea canephora* and *Coffea arabica*, found increasing CO_2 concentrations strongly mitigated the effects of high temperatures on the photosynthetic machinery of coffee plants. In what concerns the relative humidity levels (RH), the Australian cedar promoted higher values along the entire year on both distances (T1 and T2) when compared to T3 (Fig. 5). The differences between full sun exposure and shaded treatments were minimal in spring (utmost 2.4% when compared to T1 southern) and maximal in summer (up to 10.5 % when compared to T1 northern). Considering the daily RH values an inversely proportional trend to temperature variations was observed, with higher RH values in the early morning and in the late afternoon and minimal values usually in the middle of the day and early afternoon (Fig. 6). These findings are in line with other reports with shaded Conilon systems, with rubber trees (Partelli et al., 2014a) and macadamia nut trees (Pezzopane et al., 2010). Decreases in temperature, combined with both the maintenance of higher moisture levels in the air and low wind speeds, reduces the water vapour pressure deficit between the leaf and the atmosphere, and, therefore, reduces water loss by transpiration (DaMatta, 2004). Furthermore, these more temperate conditions can allow a greater stomatal aperture, favouring CO_2 uptake for photosynthesis without a proportional increase in the transpiration rate (DaMatta and Ramalho, 2006).

Growth evaluation

The implementation of shade conditions significantly increased the coffee plant leaf area irrespective of the year season (Fig. 7), when compared to unshaded conditions (T3), as also found by others (Ricci et al., 2013). The differences among seasons and orientation side (northern or southern) may be related to both the sun inclination and the irradiance level. Arabica coffee seedlings growth under different radiation levels showed increased leaf area with decreased light (Tabagiba et al., 2010), whereas Conilon plants shaded by rubber trees showed the same pattern of higher leaf area (Partelli et al., 2014a). Valladares et al. (2006) found this effect in different plant species, in which the shaded leaves exhibited increased leaf areas per unit mass because of the lower intensity of received photon flux. According to these authors, the increased leaf area is a plant acclimation strategy under low light for harvesting the greatest possible light intensity. Overall, sun-exposed leaves are smaller because the mesophyll cell arrangement increases the contact surface with the air, allowing better latent heat loss and effective foliar cooling (Rubio-de-Casas et al., 2007). The average internodes length of both plagiotropic/reproductive (Fig.8A and 9A) and orthotropic branches (Fig.8B and 9B) increased throughout the year in response to greater shading levels, as previously reported in coffee trees (Morais et al., 2003; Partelli et al.,2014a). The closer coffee plants to the Australian cedar on the southern side (T1 southern) presented higher internodes lengths in reproductive branches throughout the year (Fig.8A) and from October onwards in orthotropic branches (Fig.8B), likely related to the lower irradiance incidence for most of the evaluated dates (Fig. 1 and 2). In fact, branch elongation is caused by shading to avoid low irradiance (Ricci et al., 2006) or in environments relatively rich in far-red light under low light conditions (Morgan and Smith, 1979). Accompanying the internodes length, also the accumulated branch growth showed variations during the year depending on the different shading levels (Fig.8C, 8D, 9C and D), with increasingly differences starting immediately after the beginning of measurements. When evaluating the cumulative growth data in the last assessment for both orthotropic/reproductive (Fig.9C) and orthotropic branches (Fig.9D), there were increases in these variables according to the increases in shading levels, but there was no significant difference between the non-shade-grown coffee (T3) and the coffee row located 4.5 m from the Australian cedar on the northern side. The higher growth observed in the shaded plants is similar to the behaviour presented in the branch etiolation (Fig.9A and9B), therefore, the shaded coffee showed the highest growth from internodes elongation that was induced by low irradiance incidence (Fig. 1). Etiolation is not only related to the light quantity but also to the light quality. After passing through the leaves of the Australian cedar canopy, the spectral distribution of solar radiation changed, increasing the far-red ratio compared with the red wavelengths, promoting the conversion of far-red phytochrome into red phytochrome and reducing the ratio between far-red and total phytochrome (Morgan and Smith, 1979). On the other hand, although shade seemed to increase the number of nodes per orthotropic branch (Fig.8E), there were only non-significant changes when considering the entire year (Fig.9E), suggesting similar potential for grain production under different shading levels. In fact, the number of nodes is a good indicator of the amount of productive bud gems available, and it is considered the largest productivity component (Bonomo et al., 2004). Similar numbers of rosettes between both sun-grown and shade-grown coffee were also previously reported by Ricci et al. (2013).Higher nodes values were observed in February in orthotropic coffee branches that were located 4.5 m from Australian cedar on the southern side (T2 southern) (Fig.8F), differing statistically from coffee that was located 4.5 m away on the northern side (T2 northern) (Fig.9F).

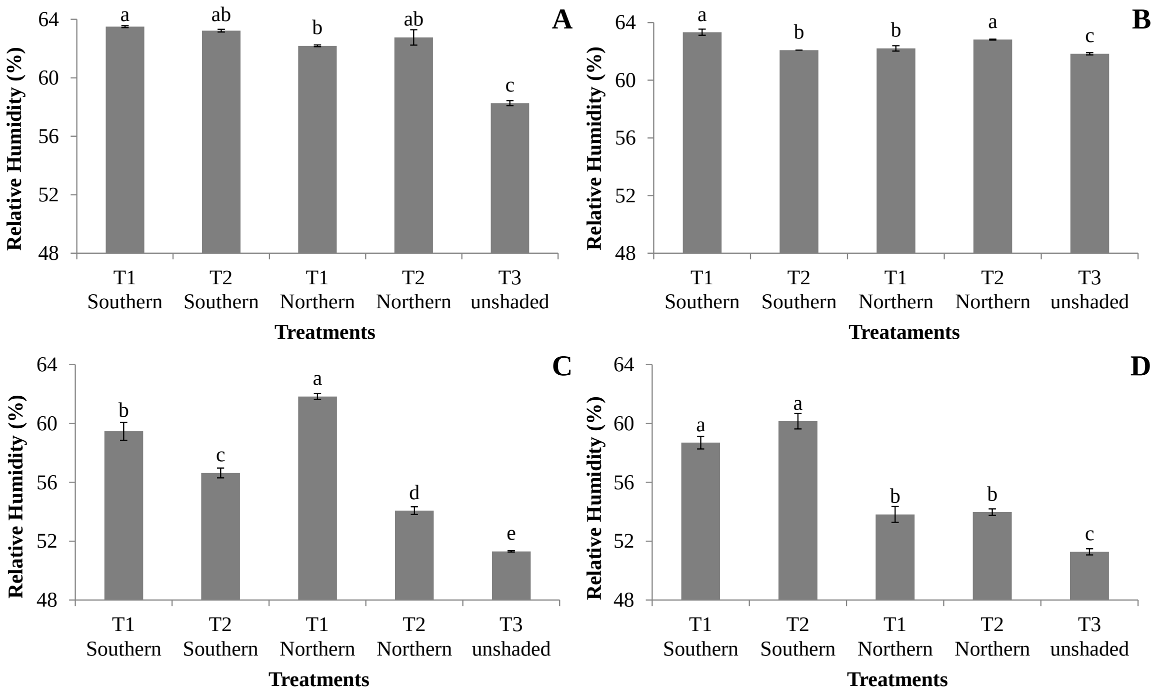

Fig 5. Average relative daily humidity in the winter (A), spring (B), summer (C) and autumn (D) on conilon coffee grown in the shade under Australian cedar, with a coffee row that was 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded). Vertical bars represent the standard error of mean. Bars followed by the same letter do not differ by Tukey's test at 5 %. CV%: winter = 0.71%; spring = 0.37%; summer = 1.02%; and autumn = 1.26%.

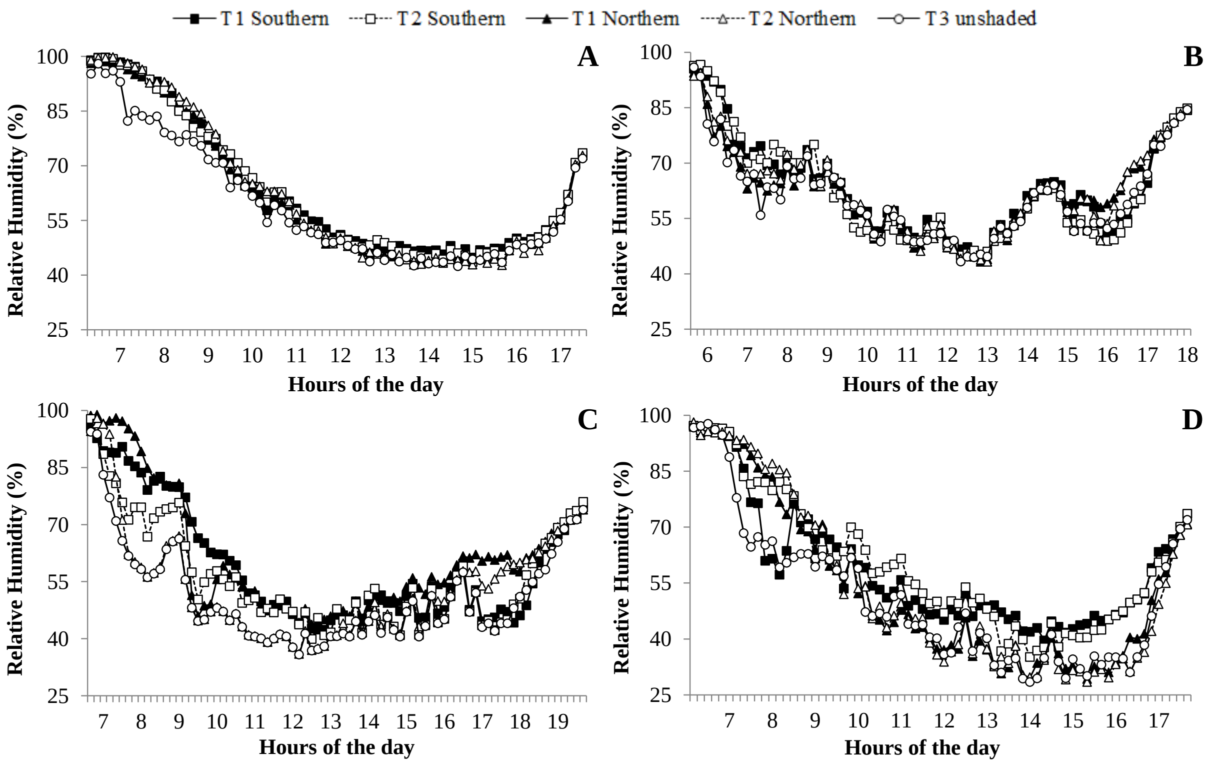

Fig 6. Average daily relative humidity during the winter (A), spring (B), summer (C) and autumn (D) on conilon coffee grown under the shade of Australian cedar with a coffee row at 1.5 m from the Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row that was 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded).

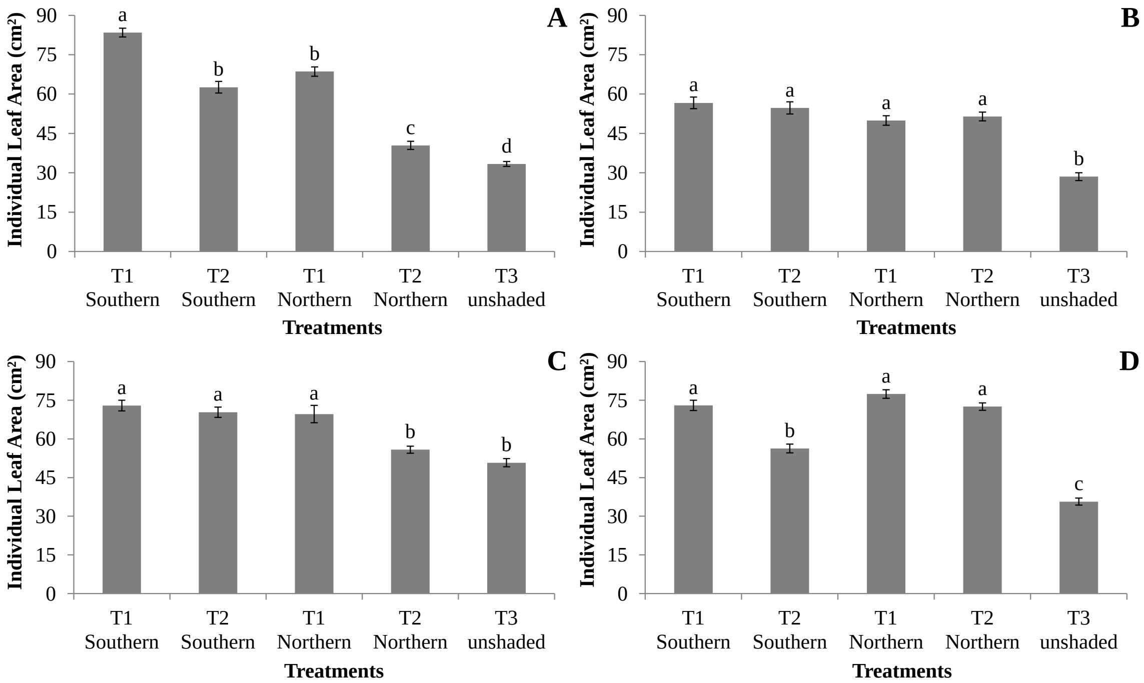

Fig 7. Average individual leaf area in the winter (A), spring (B), summer (C) and autumn (D) on Conilon coffee grown in the shade of Australian cedar with a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern),a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded). Vertical bars represent the standard error of mean. Bars followed by the same letter do not differ by Tukey's test at 5 %. CV%: winter = 20.66%; spring = 28.24%; summer = 24.38%; and autumn = 18.60%.

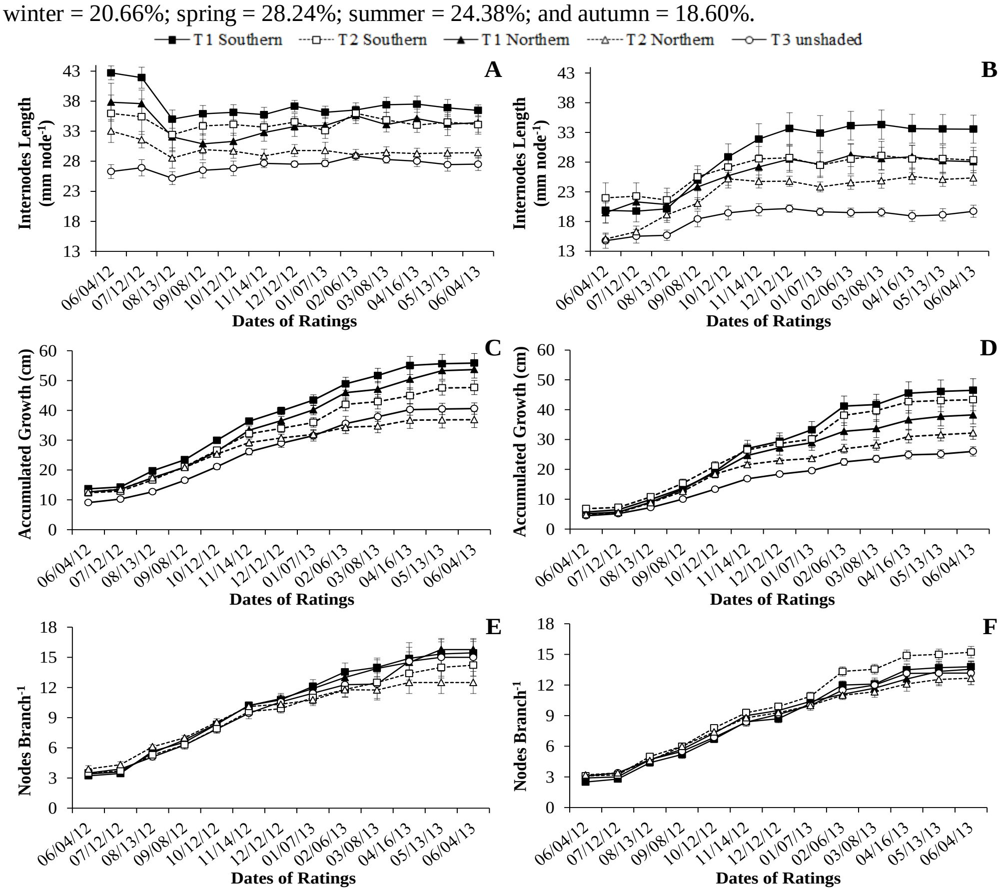

Fig 8. Average internode lengths of plagiotropic/reproductive(A) and orthotropic branches (B), the accumulated growth of plagiotropic/reproductive (C) and orthotropic branches (D), and the number of nodes per plagiotropic/reproductive (E) and orthotropic branches (F) on Conilon coffee grown in the shade of an Australian cedar with a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern), a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded).

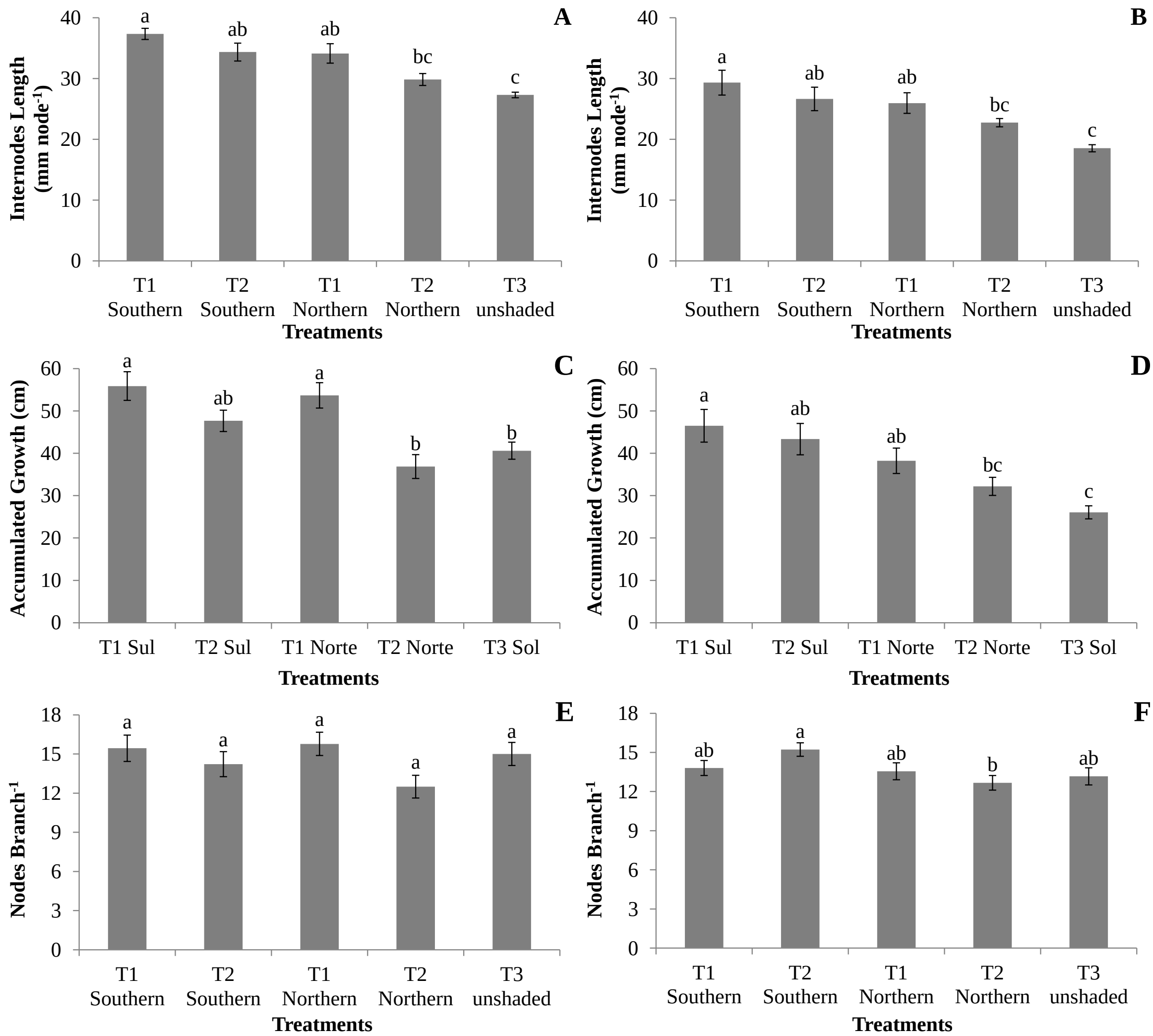

Fig 9. Average internode lengths of reproductive (A) and orthotropic branches (B), the accumulated growth of reproductive (C) and orthotropic branches (D), and the number of nodes per plagiotropic (E) and orthotropic branches (F) on conilon coffee grown in the shade of an Australian cedar with a coffee row located 1.5 m from Australian cedar on the southern side (T1 southern) and on the northern side (T1 northern), a coffee row at 4.5 m on the southern side (T2 southern) and the northern side (T2 northern), and an unshaded coffee row (T3 unshaded). Vertical bars represent the standard error of mean. Bars followed by the same letter do not differ by Tukey's test at 5 %. CV%: A = 11.3%; B = 19.6%; C = 18.7%; D = 25.3%; E= 20.1%; and F = 13.7%.

Yield

The shade provided by Australian cedar did not clearly influence the Conilon coffee yield under different shading levels, since it were obtained average yields of 88.44, 70.90, 73.36, 85.51 and 91.15 bags $ha^{-1}$for T1 southern, T2 southern, T1 northern, T2 northern and T3unshaded treatments, respectively. Similar results were observed by Partelli et al. (2014a) on Conilon coffee grown shaded by rubber trees under different shading levels. Although coffee grown in agroforestry systems associated with *Inga vera* and *Grevillea robust* tress showed higher yields than sun-grown coffee (Salgado et al., 2004), other studies have shown that shade above 80% decreases the yield (Ricci et al., 2006). It is noteworthy that there was maximum irradiance retention of 70% in the summer for coffee that was planted 1.5 m from Australian cedar, which did not influence the coffee yield in the present study. Finally, it is worth noting that on unshaded coffee (T3), the yield was similar to T1 southern, but was clearly higher than T2 southern and T1 northern treatments, what agrees with studies showing that coffee is able to cope with excess radiation provide that an adequate mineral nutrition is granted to the plants (Ramalho et al., 1998; 1999; 2000) and it explains the success of sun-grown coffee (Martins et al., 2013). However, it is necessary to emphasize the benefits of a shading system as a cultural management practice that presents the possibility of mitigating the effects of the combined effectsdrought and elevated temperatures on coffee trees (Cavatte et al., 2012). Moreover, this approach allows for the cultivation of two economic relevant crops in the same area, with Australian cedar growing with at reduced cost (data not shown).To determine the economic viability of this intercrop, we will have to account for the cedar harvest and the dilution of revenue through the cultivation years of both species. Therefore, in accounting for both socio-economic and environmental benefits, this activity has been characterized as a practice that is both viable and sustainable.

Materials and Methods

Plant material and experimental design

The experiment was performed using five years old *Coffea canephora* Pierre ex A. Froehner cv. Conilon Clone 02 plants, which belongs to the clonal variety "EMCAPA 8111" (Bragança et al., 2001), planted in 3 x 1.20 m spacing and watered, on a rural property in São Mateus area, Espírito Santo state, Brazil (18º44'S, 40º14'O), at 120 m altitude in flat relief. Together with the coffee plants, were used *Toona ciliata* M. Roem. var. Australis (Australian cedar), trees with the same age of coffee trees, planted in 15 x 2 m spacing, resulting in five rows of coffee to one row of Australian cedar. All rows were oriented 70° northwest. During the experimental trial period, the Australian cedar presented an average diameter at breast height (DBH) of *ca*. 50 cm, a height of *ca*. 12 meters and a canopy diameter of *ca*. four meters. The experiment consisted of five treatments, with four shading levels, related to the distance to the Australian cedar trees, and one in full sunlight. Two distances of the coffee to the Australian Cedar were considered (T1 at 1.5 m, and T2 at 4.5 m), on both southern and northern sides. The full exposure coffee plants (T3 unshaded) correspond to one coffee row in the adjacent area, without Australian Cedar implantation. The experimental plot consisted of 10 plants (replicates), and measurements of the leaf area, growth, branch etiolation (both on plagiotropic and orthotropic branches), number of nodes per branch, yield assessments and microclimate characterization were performed.

Microclimate characterization

The microclimate characterization included irradiance, temperature and relative humidity variables. The measurements were performed with an external data logger (HOBO U12, Onset HOBO Data Loggers, Bourne, MA, USA), placed at a 3 m height above the coffee tree rows and programmed to record data every 10 minutes during every day. Three data logger were placed in each row, resulting in three replicates per treatment. The climatic data were reported on 12/07/2012 (winter), 10/12/2012 (spring), 07/01/2013 (summer) and 04/29/2013 (autumn) between 05:00 and 19:00 on days with full sun. During this time, the apparent movement of the sun was close to 21º48" northern in the summer to 7°49" southern in the spring, to 22°15" southern in the summer and to 14°44" northern in the autumn.

Growth evaluation

Branch measurements were performed monthly for one year (04/06/2012 to 06/04/2013) with a ruler, together with the evaluation of the number of nodes on each marked branch. The average internodes length (etiolation) was obtained by dividing the branch length by the number of nodes.
Maximal length and width of the leaf blade of the leaves used to chlorophyll evaluation were measured, in order to calculate the individual leaf area, according to the Partelli et al. (2006).

Yield

The harvest of coffee bean was performed manually in 2013 for the 10 plants marked in each treatment. The average coffee seed yield was quantified in litres per plant and extrapolated to bags per hectare by using an assumption of 320 litres of coffee cherries per 60 kg bag^{-1} when processed, accounting for yields.

Statistical analysis

The microclimate, leaf area, relative chlorophyll index and yield data were subjected to an Analysis of Variance and the means were compared by Tukey's test at 5% probability with the Assistat program (Silva and Azevedo, 2009).

Conclusions

Shading Conilon coffee with Australian cedar decreased the irradiance and temperature and increased the relative humidity values during the day in most time periods, providing a milder environment for cultivation. This shading led to higher growth and etiolation in both the plagiotropic and orthotropic branches of the coffee trees and higher leaf expansion, demonstrating adaptation to low light, and it did not influence the number of nodes per branch or the coffee yield, although the plants under full sun exposure showed the highest yield values, significantly to some shading treatments. Shading Conilon coffee with Australian cedar under the conditions studied here showed intercropping potential and it simultaneously allows for wood production.

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