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Physiological characteristics and development of coffee plants under different shading levels

ABSTRACT

Differences in the availability of solar radiation can cause modifications in the structure and function of coffee plant leaves, such as physiological, growth and disease incidence alterations. The objective of this work was to evaluate the physiological characteristics and development of developing coffee plants submitted to five shading levels (0, 35, 50, 65 and 90% of shading) in the dry and rainy period. The evaluations were conducted in coffee plants of the *Coffea arabica* L. species, cultivar Catucaí Amarelo 2SL. The treatments were disposed in a randomized block design with plots subdivided in time, in which the shading levels and the evaluation periods were disposed in the plots and split-plots, respectively. The different shading levels and the seasonal modifications (rainy and dry period) to which the coffee plants were submitted promoted effects on the physiological characteristics, presenting better photosynthetic performance under 35, 50 and 65% shading levels in the rainy period. However, in the dry period, the plants submitted to the 50% shading level present higher CO_2 assimilation. The 35, 50 and 65% shading levels provide better growth for coffee plants. Coffee plants under full sun present higher cercosporiosis incidence.

Key words: *Coffea arabica* L., cercosporiosis, photosynthesis.

Características fisiológicas e desenvolvimento de cafeeiros sob diferentes níveis de sombreamento

RESUMO

Diferenças na disponibilidade de radiação podem causar modificações na estrutura e função das folhas do cafeeiro, como alterações fisiológicas, no crescimento e na incidência de doenças. O objetivo deste trabalho foi avaliar as características fisiológicas e o desenvolvimento de cafeeiros em fase de formação, submetidos a cinco níveis de sombreamento (0, 35, 50, 65 e 90% de sombra) no período seco e chuvoso. As avaliações foram realizadas em cafeeiros da espécie *Coffea arabica* L. da cultivar Catucaí Amarelo 2SL. Os tratamentos foram dispostos no delineamento em blocos casualizados com parcelas subdivididas no tempo, sendo os níveis de sombreamento e as épocas de avaliação dispostos nas parcelas e subparcelas, respectivamente. Os diferentes níveis de sombreamento e as modificações sazonais (período chuvoso e seco) aos quais os cafeeiros foram submetidos promoveram efeitos sobre as características fisiológicas, apresentando melhor desempenho fotossintético sob os níveis 35, 50 e 65% de sombreamento no período chuvoso. Já no período seco, as plantas submetidas ao nível de 50% de sombra apresentam maior assimilação de CO_2. Os níveis de 35, 50 e 65% de sombreamento proporcionam melhor crescimento dos cafeeiros. Plantas de cafeeiro a pleno sol apresentam maior incidência de cercosporiose.

Palavras-chave: *Coffea arabica* L., cercosporiose, fotossíntese.

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Introduction

The effects of radiation levels on the physiology of coffee plants are important, once the *Coffea arabica* L. species come from Ethiopian forests, where it can be found under the protection of trees (Gomes et al., 2008). Early coffee plantations were shaded by planting trees to simulate their natural habitat. However, in many situations, the coffee plant grew and had better production without shading. As a result, shading was abandoned in regions (DaMatta et al., 2007; Chaves et al., 2008) at the same time in which cultivars were being genetically improved to present high production under full sun conditions (DaMatta, 2004; Kanten & Vaast, 2006; Gomes et al., 2008).

This cultivation system under full sun has been successful due to the high phenotypic plasticity of the coffee tree plants in acclimating to different radiation levels (Fahl et al., 1994; Carelli et al., 1999). Several characteristics can be associated with acclimatization to high radiation, such as: palisade and spongy parenchyma thickness, stomatal dimensions (Ramiro et al., 2004; Pinheiro et al., 2005; Nascimento et al., 2006; Batista et al., 2010; Pompelli et al., 2010a), lower chlorophyll content per mass unit, higher nitrogen concentration per leaf area (Araújo et al., 2008), among others.

However, it is observed that effect of shading on the photosynthetic rates of coffee plants has been showing contradictory results. An increase in the net assimilation of CO_2 was observed in coffee plant leaves under high radiation when compared with shaded leaves exposed to lower radiation (Friend, 1984; Fahl et al., 1994; Morais et al., 2003; Nascimento et al., 2006; Araújo et al., 2008; Gomes et al., 2008; Chaves et al., 2008). Nevertheless, other authors found that coffee plants under shading present higher photosynthetic rates (Nutman, 1937; Kumar & Tieszen, 1980; Freitas et al., 2003). Kumar & Tieszen (1980), for instance, verified that the photosynthetic rate of shaded plants is almost twice as the ones of plants under full sun.

Most studies have focused on the use of natural shading obtained by forestation or by the coffee plant canopy itself. There are few studies that approach developing coffee plants under artificially shaded systems in field conditions. Artificially shaded systems make possible to determine with higher precision the shading level which becomes harmful to the coffee plant, once the shading effect is isolated. Furthermore, artificially shaded systems allow verifying if the advantages obtained with the use of shading are due to the isolated shading or to the effects of the agroforestry systems that, besides reducing the radiation, also alter the microclimate and the water balance of the crop, with indirect effects on the water availability in the soil and atmosphere.

The characterization of shading effects on the physiology of coffee plants is important to determine optimum levels of radiation, as well as to subsidize studies on growth and cercosporiosis incidence of shaded plants, aiming at determining the ideal coffee plant architecture that maximizes the absorption of the available solar radiation in shaded environments. In this context, the objective of this work was to evaluate the physiological characteristics and development of developing coffee plants submitted to different shading levels in the dry and rainy periods.

Material and Methods

The experiment was carried out in the Coffee Sector of the Department of Agriculture of the Federal University of Lavras, located in Lavras, Minas Gerais, Brazil (21°14' S latitude and 45°00' W longitude at an average altitude of 915 m). The climate of the area is classified as the Cwa type, according to Köppen, but it presents Cwb characteristics, with two different seasons: dry (April to September) and rainy (October to March). The monthly values of relative air humidity (%) and average temperature (°C) were observed during the evaluation of the treatments (Figure 1).

Evaluations were conducted in coffee plants of the *C. arabica,* 'Catucaí Amarelo 2SL' species. The field experiment was installed in January 2009 at a 2.5 x 0.7 m spacing. After the planting, the coffee plants were submitted to five shading levels, under full sun and under plastic screens providing 35, 50, 65 and 90% shading. Four repetitions were used, totaling 20 plots. Each plot was composed of a row with ten plants, and the six central plants were considered as useful. The gas exchange, growth characteristics and cercosporiosis incidence on the plants were evaluated in the 2010 rainy and dry seasons. The gas exchange measurements were carried out 12 and 19 months after setting up the shading levels on the field. The growth and cercosporiosis incidence assessments were conducted 13 and 18 months after the beginning of the field experiment.

The gas exchange evaluations were conducted with a portable infrared CO_2 analyzer (IRGA LCA-4 ADC Hoddesdon, UK), mostly on clear typical days, between 10 and 11 a.m., in completely expanded leaves (third pairs of leaves of the plagiotropic branch, from superior third). One leaf per plant and six plants per treatment were used.

The following growth characteristics were evaluated: plant height, number of plagiotropic branches and stem diameter.

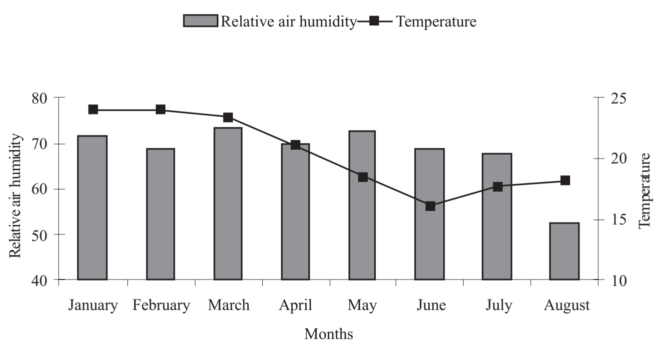

Figure 1. Average temperature and relative air humidity in the period from January to August 2010 at the Climatological Station of the Federal University of Lavras.

Figura 1. Temperatura média e umidade relativa do ar no período de janeiro a agosto de 2011 na Estação Climatológica da Universidade Federal de Lavras.

The measurements of the stem diameter were made at the collar of the plants with a caliper rule (mm).

The cercosporiosis incidence was evaluated through the analysis of 20 leaves at random in the parcels. The incidence of the disease in those leaves was identified and determined through the percentage of infected leaves. The disease incidence percentages were transformed in the area under the disease progress curve (AUDPC) according to Campbell & Madden (1990).

Treatments were arranged in a randomized block design with plots subdivided in time, whereas the shading levels and the evaluation periods were disposed in the plots and sub-plots, respectively. The variance analysis was carried out for all the studied characteristics, and when significant, the variables were submitted to the regression analysis, using the SISVAR software (Ferreira, 2003).

Results and Discussion

The use of plastic screens, with the intention to cause gradual reductions in the solar radiation available to the plants, was adapted for the purposes of this work, since it was observed that the seasonal average of *photosynthetically active photon* flux density decreased with the increase of the shading level (Figure 2A). The *photosynthetic photon* flux density was higher in the rainy season in all treatments, reaching a maximum value of 1,850 μmol m^{-2} s^{-1}, while in the dry season, the highest value obtained was 1,150 μmol m^{-2} s^{-1}. The leaf temperature, for both seasons, presented the same behavior, having the highest leaf temperatures occurring under full sun, followed by the 35, 50 and 65 % shading levels, and the lowest temperatures under the highest shading, 90% (Figure 2B). Similar behavior was observed in artificially

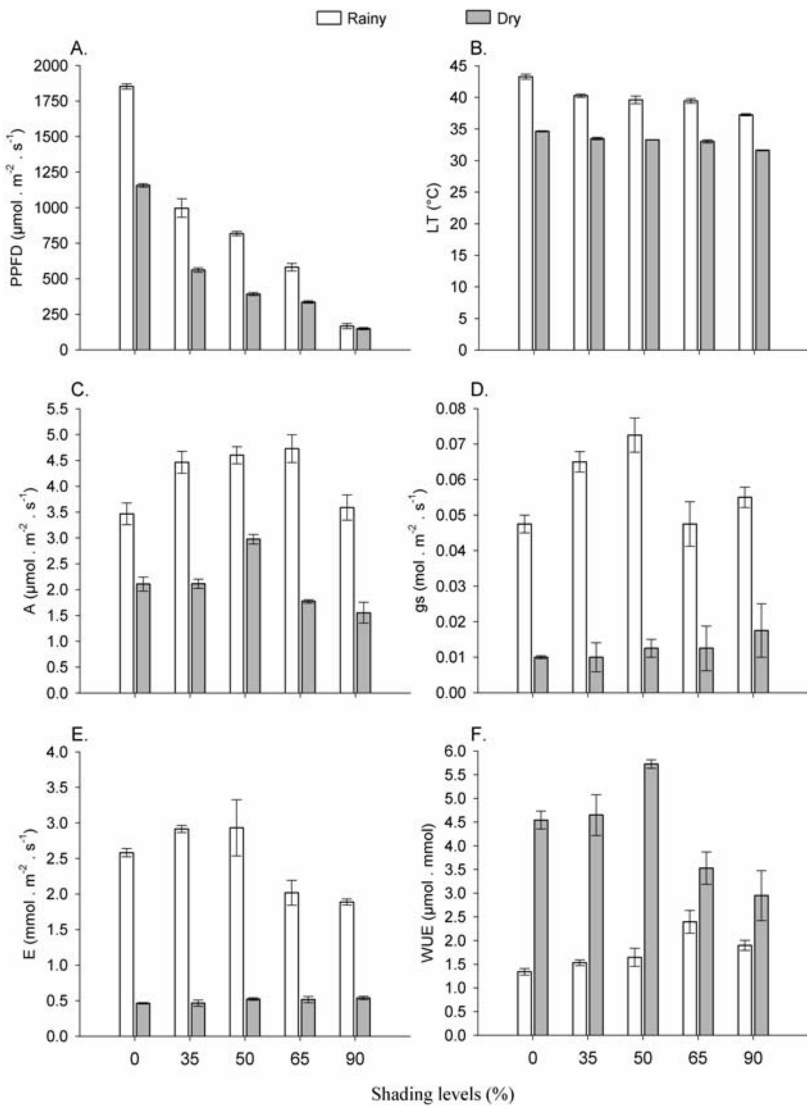

Figure 2. *Photosynthetically active photon* flux density (PAPFD), leaf temperature (LT), photosynthesis (A), stomatal conductance (gs), transpiration (E) and water use efficiency (WUE) in the rainy and dry seasons for coffee plants, under different shading levels. Bars represent the standard error of the mean (n = 6)

Figura 2. Densidade de fluxo de fótons fotossinteticamente ativos (DFFFA), temperatura foliar (LT), fotossíntese (A), condutância estomática (gs), transpiração (E) e eficiência do uso da água (WUE), observados na época chuvosa e seca para cafeeiros, submetidos a diferentes níveis de sombreamento. Barras representam o erro-padrão da media (n = 6) shaded coffee seedlings and in developing coffee plants cultivated under dense shading with *Cajanus cajan* L. and under full sun (Freitas et al., 2003; Morais et al., 2003).

It was observed that the 35, 50 and 65% shading levels favored the photosynthetic process in the rainy season (Figure 2C). However, for the dry season, the 50% shading level enabled a higher CO_2 assimilation (Figure 2C). Similar results were obtained by Pompelli et al. (2010a) in which the coffee plants grown under 50% shading showed higher photosynthetic rate values compared to plants grown under full sun, during winter conditions. The photosynthetic rate depends on the season, since the low temperatures observed in the dry season can modify the behavior of the coffee plants, decreasing their photosynthetic rates.

Several authors (Friend, 1984; Fahl et al., 1994; Morais et al., 2003; Nascimento et al., 2006; Araújo et al., 2008; Gomes et al., 2008; Chaves et al., 2008) observed an increase in the photosynthetic rate of coffee plant leaves under high radiation when compared with exposed shaded leaves. However, other authors found that coffee plants under shading present higher CO_2 assimilation (Nutman, 1937; Kumar & Tieszen, 1980; Freitas et al., 2003). These contradictory results may be due to the methodological differences between the conducted works. For studies of this nature, some factors that affect the physiological processes of coffee plants should be considered, such as climatic conditions (temperature and radiation), experimental conditions (pot or field), plant age, genotype and its adaptability to the local climate, shading type (natural or artificial), used species and shading density (Carelli et al., 1999; Morais et al., 2003).

Between the seasons, for all treatments, a significant reduction of the photosynthetic rates were verified in the dry season (Figure 2C.), indicating that low night temperatures may largely depress in stomatal conductance, even when the daytime temperature is adequate for gas exchange in coffee plants (DaMatta et al., 1997; Ramalho et al., 2003; Silva et al., 2004; Pompelli et al., 2010b).

In the rainy period, the 35 and 50% shading levels provided the highest stomatal conductance values, being superior to the other shading levels (Figure 2D.). These results corroborate those obtained by Carelli et al. (1999), who observed that the reduction of stomatal conductance values occurs starting from 50% shading.

The lowest transpiration values in the rainy period were found in the highest shading levels (65 and 90%), an indication of higher environmental stress under non-shaded conditions, a fact already observed in coffee grown under *Cajanus cajan* L. shading (Morais et al., 2003) (Figure 2E). The lowest values of stomatal conductance, as well as of transpiration, were found in the dry season in comparison to the rainy season, without significant differences between the shading levels. This fact can be explained by temperature decrease, as already discussed.

The lowest water use efficiency was found in the rainy period, with prominence for the 65% shading level in relation to the other treatments. In the dry period, the highest value occurred at 50% shading, followed by the 0 and 35% shading levels, while the lowest values were presented in higher shading levels, 65 and 90% (Figure 2F). Similar results were found by Carelli et al. (1999), in which the efficient water use was higher in the plants under full sun and 50% shading, followed by 80% shading.

Regarding the growth evaluations, for all the analyzed variables, it was observed that the dry period presented the highest values in comparison to the rainy period, due to the evaluations in the dry season (July) having been conducted five months after the rainy season evaluations (February).

The 35, 50 and 65% shading levels increased plant height (Figure 3A). On the other hand, the plant diameter and plagiotropic branches number were decreased only in the 90% shading level (10% solar radiation), with a tendency to thinner diameters and lower branches number (Figure 3B.C). It was observed that these results partly coincide with some physiological characteristics evaluated, mainly if compared in the rainy season (Figure 2C). Thus, the increased photoassimilates synthesis elevate the vegetative growth (Melo et al., 2008).

Fahl et al. (1994), Carelli et al. (1999) and Paiva et al. (2003) also observed that the highest shading levels reduced the *C. arabica* growth. The excessive shading reduces the quality of the transmitted radiation, which affects the physiological processes of the plant such as photosynthesis and growth (Morais et al., 2003). However, Braun et al. (2007) verified higher plant height in *Coffea canephora* seedlings submitted to 75% shading. Kanten & Vaast (2006) verified higher stem diameter of shaded coffee plants, although a higher plagiotropic branches number was observed in coffee plants grown under full sun (Morais et al., 2003). However, Kanten & Vaast (2006) and Morais et al. (2003) only evaluated the presence and absence of shading, without evaluating the influence of different shading levels.

For the area under the disease progress curve (AUDPC) lower cercosporiosis incidence was noticed in plants submitted to different shading levels (35, 50, 65 and 90%), confirming the supposed relationship that higher radiation levels increase the disease incidence (Figure 4). The treatment under full sun did not provide good coffee plant protection, obtaining the highest cercosporiosis incidence. These results corroborate those of Salgado et al. (2007), in which the authors verified that the cercosporiosis incidence was directly affected by the afforestation of the coffee plantation. The main causes of accentuated cercosporiosis intensity are associated to the water deficit and unbalance or deficiency of some nutrients. Thus, the coffee plant under full sun would probably be more susceptible to the cercosporiosis incidence due to lower soil moisture, as a result of the direct exposure to the sun under this system. Higher soil moisture of shaded system increases water and nutrient uptake over time, decreasing the cercosporiosis incidence in coffee plants (Salgado et al., 2007).

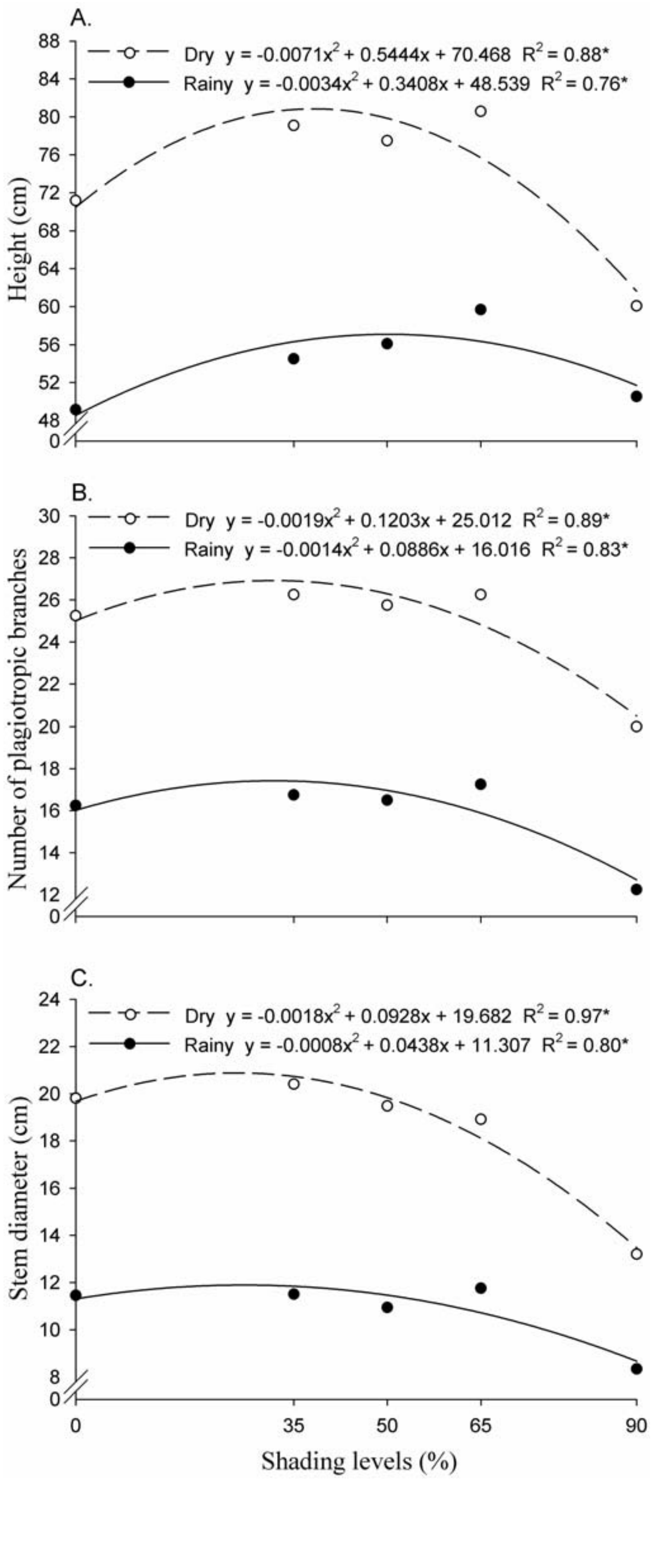

Figure 3. Plant height, plagiotropic branches number and stem diameter in the dry and rainy season for coffee plants, under different shading levels. *Significant at 5% of probability

*Figura 3. Altura de plantas, número de ramos plagiotrópicos e diâmetro do caule, observados na época seca e chuvosa para cafeeiros submetidos a diferentes níveis de sombreamento. *Significativo a 5% de probabilidade*

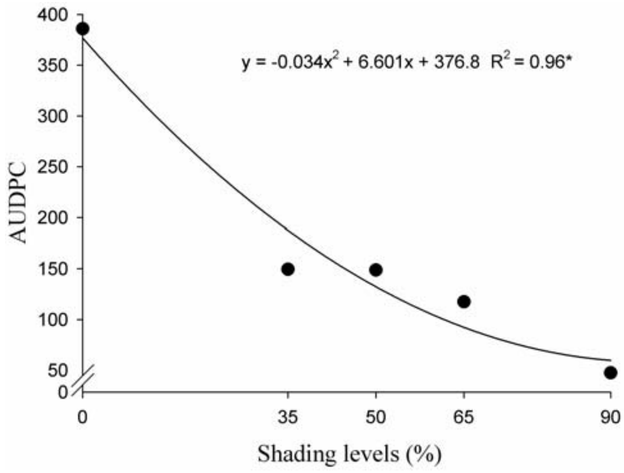

Figure 4. Area under the disease progress curve (AUDPC) in the dry and rainy season for coffee plants, under different shading levels. *Significant at 5% of probability

*Figura 4. Área abaixo da curva de progresso da doença (AUDPC), observadas na época seca e chuvosa para cafeeiros submetidos a diferentes níveis de sombreamento. *Significativo a 5% de probabilidade*

Conclusions

The different shading levels and seasonal modifications (rainy and dry periods) promoted effects on the physiological characteristics, presenting better photosynthetic performance under 35, 50 and 65% shading levels in the rainy period. However, in the dry period, the plants submitted to the 50% shading level presented higher CO_2 assimilation.

The 35, 50 and 65% shading levels provide better growth of developing coffee plants.

Coffee plants under full sun present higher cercosporiosis incidence.

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