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Shade influence of the temporary canopy of an agroforestry system on coffee fruit ripening

Paulo Henrique Marquezine Leite[1], Renata Evangelista de Oliveira[2], Ademir Durrer Bigaton[3], Gabriela Vilela[4], Anastácia Fontanetti[5]

[1]Universidade Federal de São Carlos/UFSCar, Centro de Ciências Agrárias/CCA, Programa de Pós-graduação em Agroecologia e Desenvolvimento Rural/PPGADR, Araras, SP, Brasil
[2]Universidade Federal de São Carlos/UFSCar, Centro de Ciências Agrárias/CCA, Departamento de Desenvolvimento Rural/DDR, Araras, SP, Brasil
[3]Gênica Inovação Biotecnológica, Piracicaba, SP, Brasil
[4]Universidade Estadual Paulista/UNESP, Programa de Pós-graduação em Ciências Ambientais/PPGCA, Sorocaba, SP, Brasil
[5]Universidade Federal de São Carlos/UFSCar, Centro de Ciências Agrárias/CCA, Departamento de Desenvolvimento Rural/DDR, Araras, SP, Brasil
Contact authors: paulohenriquemleite@gmail.com; reolivei@ufscar.br; demadurrer@yahoo.com.br; gabri.vilela.c@gmail.com; anastacia@ufscar.br
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ABSTRACT

In Brazil, coffee trees have been included in agroforestry systems, especially owing to climate emergencies and increased demand for specialty coffees. Shading levels in agroforestry systems (AFS) depend on the design, management and, particularly, on the development and evolution time of the system. Understanding these variations over time, as well as the effects of temporary canopy on coffee production components, can contribute to the creation of more efficient agroforestry designs, especially at the establishment stage. For this reason, this study aimed to assess levels of shading and their influence on the ripening of Yellow Bourbon coffee fruits (*Arabica coffee* L.). in a four-year-old young agroforestry coffee plantation undergoing stratification and establishment with a temporary canopy formed by *Ricinus communis* L, the main responsible for the shading of the coffee trees in the moment studied. Shading was established at four distances: 1 m (D1), 4 m (D2), 7 m (D3) and 10 m (D4), from the sunniest edge (north face) to the interior of the AFS. Different levels of shading were assessed by calculating the difference in photosynthetically active radiation (PAR) under full sun and inside the ASF. Also, total fruit volume, dry fruit percentage and dry biomass of the coffee trees were determined. The greater the edge-to-interior distances in the AFS, the greater the shading level, due to sum of the *Ricinus spp.* shadows*,* the self-shading of the coffee trees and the banana trees shadows (mainly for distances D4). The study coffee trees responded evenly within each distance; the more shaded ones produced a greater fruit volume and a lower dry fruit percentage. Coffee dry biomass was greater at distance D4. This study can provide further insights into how environmental factors, design and management of agroforestry systems, can affect coffee fruit ripening - a crucial factor for harvesting planning and production of high-quality coffee.

Key words: Multistrata agroforestry; Biomass; Agroforestry management; Photosynthetically active radiation.

1 INTRODUCTION

The cultivation of coffee in Brazil has developed extensively in full sun environments, with cultivars selected for high yield in monocultures and intensive use of inputs (Valentini et al., 2010). However, in recent decades, there has been a greater number of shaded coffee crop fields, ranging from simpler systems, with one or few shading species, to multistrata agroforestry systems (AFS) (Perfecto et al., 2005). The change in production systems was driven, in part, by the need to develop models that can adapt to climate emergencies, as it is estimated that there will be a reduction of approximately 60% of areas in the Southeast of the country whose temperature (average of 23 °C) and humidity are suitable (water deficit less than 150 mm per year) for production of Arabica coffee (Assad et al., 2004; Gomes et al., 2020).

According to Jaramillo-Botero et al. (2006), shading of coffee plantations is a very common technique, and it is indispensable in some countries in the north of Latin America. In these countries, production systems are diverse, and they can generally be classified into two types: traditional (those with little use of external inputs and high level of shading, thus forming a large number of poorly managed tree species), and intensive (highly productive systems with intensive use of external inputs, with intercropping between coffee trees and other tree species of interest, with constant pruning to increase soil fertility, or intercropping with fruit and timber trees for economic purposes).

The appropriate design and management of coffee AFS can offer several benefits, e.g., to improve microclimate conditions by reducing wind speed (Pezzopane et al., 2010), reducing average air and ground temperatures (Ehrenbergerová et al., 2017), decreasing thermal amplitude (Pezzopane, et al., 2011a), and increasing night temperatures (Siles; Harmand; Vaast, 2010). The reduction in daytime temperature reduces the deficit in saturated steam (Pezzopane et al., 2011b), enabling the optimization of solar radiation (Charbonnier et al., 2017) and water use (Cannavo et al., 2011).

Trees can also help to optimize fertilization of coffee plants, reducing nutrient losses (Tully; Lawrence; Scanlon, 2012), thus improving soil fertility (Campanha et al., 2007). In fact, shaded coffee plantations can optimize crop yield by reducing the need for inputs (Valencia; Mestre-Mestre, 2004) and minimizing the effects of the biennial production cycle of coffee (Jaramillo-Botero et al., 2010). Additionally, according to Meylan et al. (2017), they can offer ecosystem services, such as regulation (biological nitrogen fixation) and support (greater water infiltration and litter accumulation). The lower environmental impact of these production systems, allows the exploration of more profitable market niches (Teixeira; Caixeta, 2009).

In multistrata agroforestry systems (Vieira et al., 2007), which are object of this study, it is assumed that the occupation of the strata by species with different life cycles, growth speed and architectures (shoot and root), with complementary functions within the system, can optimize the use of natural resources, e.g., water, light and nutrients (Davis et al., 2019; Oliveira; Carvalhaes, 2016).

Shading can also help to improve the beverage quality of coffee (Bote; Jan, 2017) by increasing bean weight (Vaast et al., 2006) and delaying fruit ripening (Muschler, 2001) - a fact particularly attributed to a lower thermal amplitude in shaded agroecosystems.

Air temperature is considered to be the most important factor for coffee fruit ripening (Pezzopane et al., 2003). However, according to Petek, Sera and Fonseca (2009), water availability also has a strong influence on fruit ripening, and lower water availability may accelerate the ripening process.

During the dry season, evapotranspiration from trees may reduce water availability, especially in the deeper layers of the soil (Siles; Harmand; Vaast, 2010), accelerating the ripening of coffee fruits. Da Silva Neto et al. (2018), when analyzing the ripening rate of coffee fruits in an agroforestry system on the basis of tree-to-tree distance, found a higher percentage of dry fruits close to the trees, even with the highest shading rate. One of the hypotheses was that competition for water near the trees may have accelerated ripening.

Particularly in multistrata AFS, there are important temporary effects of species from intermediate strata at the initial stages of establishment of the system, when since tree species cannot yet effectively shade coffee trees. There are few studies on shading of coffee plantations in AFS, especially on the effects of shading species and their interactions, and their influence within the agroecosystem over time, which can be analyzed using photosynthetically active radiation measurements.

Therefore, this paper aimed to evaluate the effects of shading provided by the temporary canopy formed by *Ricinus communis* L in a multistrata successional agroforestry system, in a stratification/establishment process, on fruit ripening in a young (four-year-old) coffee plantation. It is assumed that the results originate from a one-off analysis of the system, based on the quantification of photosynthetically active radiation (PAR) available in the fruit ripening phase, at different shading levels in the AFS. The present study proposes to discuss the results based on the history, evolution and management of the study system, as well as the effects of shading on coffee fruit ripening in multistrata agroforestry systems.

2 MATERIAL AND METHODS

2.1 Study agroecosystem

The experiment was conducted from August 2019 to June 2020, on Sítio Providência farm, located in the municipality of Poços de Caldas, southern Minas Gerais, Brazil, latitude 21°46’19” South, longitude 46°27’09” West, at an altitude of 1000 meters. The region has tropical highland climate (Cwb), according to Köppen classification (1948).

The area of choice was a plot grown under organic management since 2016, with an area of 1,050 m^2 (15 m x 70 m) and 300 plants of Arabica coffee var. Yellow Bourbon, spaced at of 2.6 x 1.3 meters, in 30 planting rows with north to south orientation. The north face is bordered by a road, has no windbreaks, and has high solar incidence. The south face, on the other hand, has a double row of banana trees (*Musa paradisica* L. var. Prata).

The area is located on a medium plateau where regolithic Cambisols predominate, and it has a clayey texture (Moraes; Jiménez-Rueda, 2008). The analysis of the chemical characteristics of the soil in the year of the experiment showed the following results: Organic matter = 0.65 dag kg^{-1}, K = 75 mg dm^{-3}, P = 12.97 mg dm^{-3}, S = 7.4 mg dm^{-3}, Ca = 3.01 cmolc.dm^{-3}, Mg = 0.83 cmolc.dm^{-3}, pH in $CaCl_2$ = 5.2 and CEC at pH 7.0 =7.08. Figure 1 shows water balance and average temperature values during the study period.

2.2 Design and history of the AFS

The coffee trees were planted in December 2015, at a density of 3000 plants (2,6 m x 1,3 m). Were then sown, between the coffee rows, every 0.5 meters, Guandu seedlings (*Cajunus cajan* L.). Thinning was performed to leave one plant every meter, on both sides of each coffee tree, forming a tunnel. This was done to provide a suitable microclimate for plant development and increase nutrient cycling and soil fertility.

The ultimate objective was to form a multistrata agroforestry system, with four strata established in addition to the coffee trees: an emergent one, formed by large-sized legumes trees (Fabaceae) with a wide crown and small leaves; a canopy evergreen stratum; a medium one, composed of deciduous legumes; and a low stratum composed of service trees.

The tree species were planted between the rows of the coffee trees in December 2016, after the tunnel of guandu plants had been cut. All specimens were planted in the same period and were grown to compose a multistrata agroforest, as shown in Figure 2.

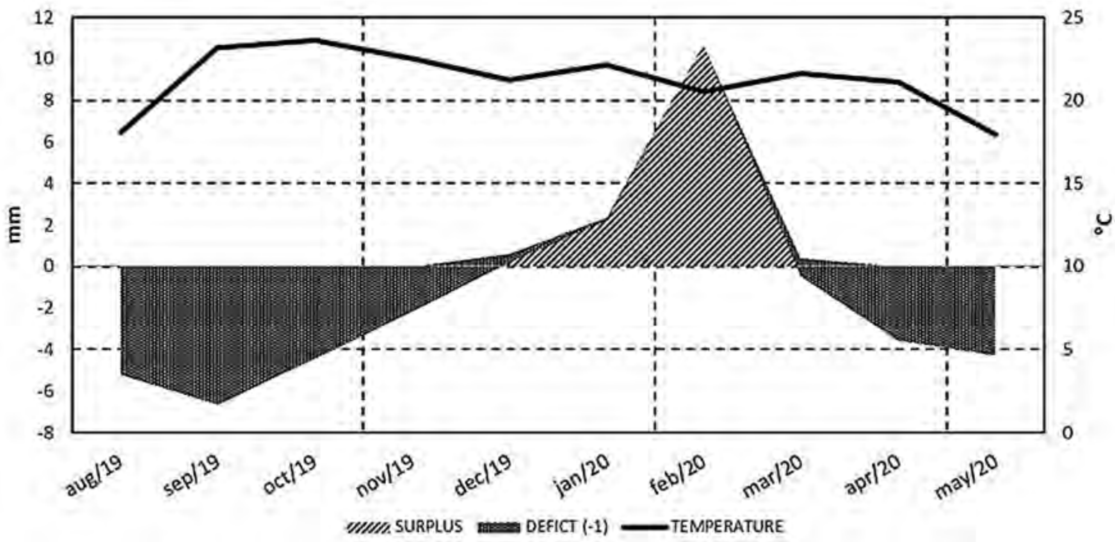

Figure 1: Water balance and average temperature during the study period. Values collected from a meteorological station located in Caldas/MG- Brazil, 25 km away from the experiment. Data source: Brazil's National Institute of Meteorology (INMET).

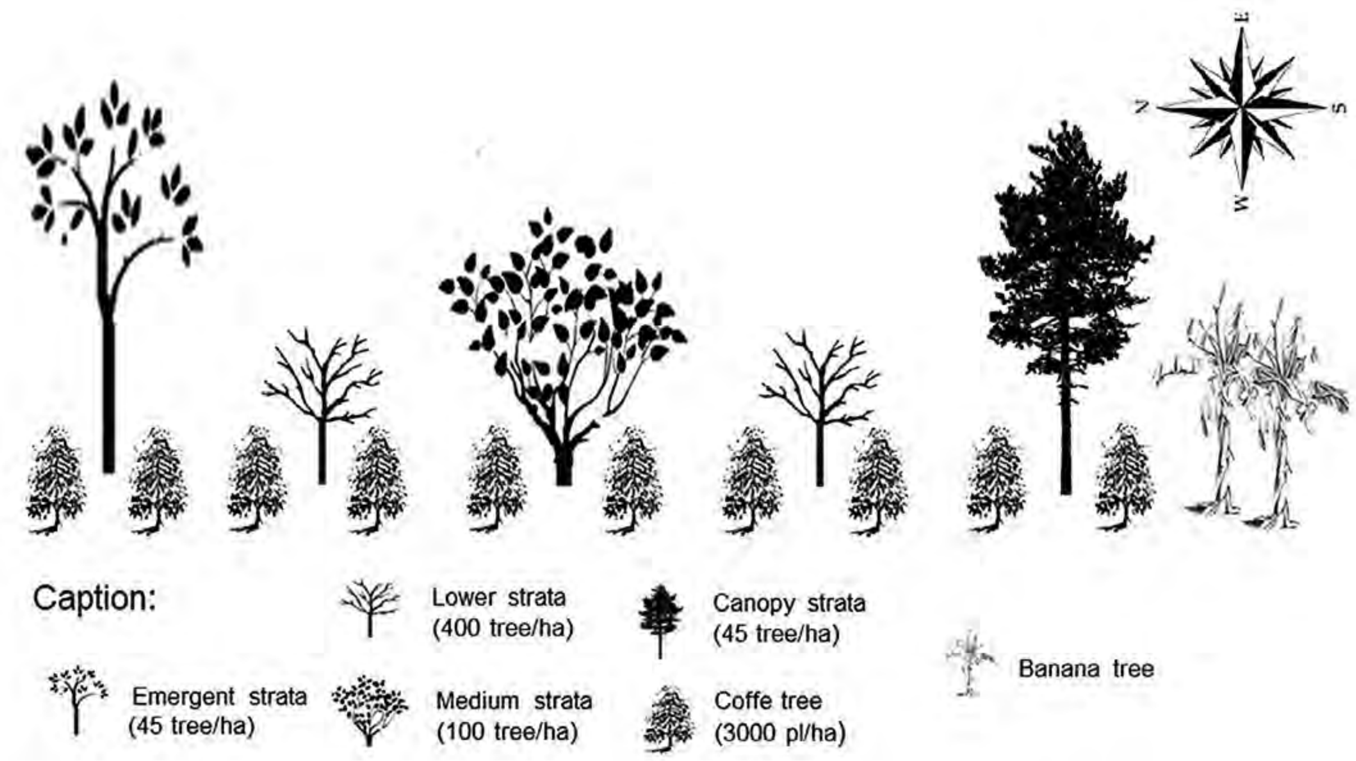

Figure 2: Cross-section profile of the AFS studied to be formed after the trees grows. Species from the emerging stratum: *Anadenanthera colubrina* (Vell.) Brenan (Red Angico) and *Enterolobium contortisiliquum* (Vell.) Morong (earpod tree); upper stratum species *Aspidosperm cylindrocarpon* Muell. Arg (Peroba-poca) and *Grevilea robusta* A. Cunn. L (southern silky oak); lower stratum species *Platycuamus Regnellii* Benth (Pau Pereira), *Myrocarpus frondosus* Allemão (cabreuva) and *Centrolobium tomentosum* Guillemin ex Benth (Araribá-rosa); lower stratum species *Lonchocarpus guillemineanus* (Tull.) Malme (lancepods), *Citharexylum myrianthum* Cham (fiddlewoods) and Inga vera Willd (silky inga).

The coffee trees were pruned at 0.30 m from the ground in October 2018 to grow 3 to 5 stalks per plant, for use of programmed cycle pruning (Verdin et al., 2016).

For the training of the trees and temporary shading of the coffee trees, a *Ricinus communis* L. plant (Castor bean) was planted every 4 meters between the rows of the trees, in

December 2018 – in a total of 960 plants per hectare. *Ricinus spp*. Is a fast-growing species, and at the time of evaluations, it was about three meters high, closing the canopy of the agroecosystem. Therefore, at that time of evaluation, prior to the establishment of the treetops, it formed the temporary agroforestry canopy. The use of *Ricinus spp*. at the early stages of coffee farming is also performed in Turrialba, Costa Rica (Schnabel et al., 2018) to stimulate coffee tree growth and reduce weed density.

The *Ricinus spp*. plants were pruned for the first time in October 2019, when they were about 1.3 m tall (as tall as the coffee trees). Side branches were cut off, and only the shoots above the coffee trees were left. In March 2020, prior to the evaluations, the *Ricinus spp*. plants had already grown 1.5 meters above the crowns of the coffee trees, closing the canopy. At such moment, the crowns were pruned, and only four main branches were left. Figure 3 shows the main stages for implementation and management of the AFS, including the times of assessment.

2.3 Crop growing practices

In the 2019-2020 agricultural year, liming (350 g of limestone per plant) and application of 10 g of ulexite (10% boron) per coffee tree were carried out, respectively, in August and September. Organic fertilization was carried out in November 2019 with 200 g of meat and bone meal and in December 2020, with 200 g of castor bean cake. In December 2019 and February 2020, Bordeaux mixture was sprayed. Weeds were managed on a monthly basis with a backpack mower.

2.4 Experimental design

Coffee trees located at four distances were selected during a transversal walk within the AFS: 1 m (D1), 4 m (D2), 7 m (D3) and 10 m (D4) from the sunniest edge (north face) to the interior of the AFS. Ten repetitions were performed. One coffee tree was sampled per distance (10 rows of plantations with 4 coffee trees each, one per distance) (Figure 4). The plots were located in the 20 central rows of the plot, and the coffee trees were evaluated in alternate rows. Therefore, there was a total of 40 coffee trees in 8 rows. Sampling covered about 33% of the planting rows of the AFS and 13% of the coffee trees.

2.5 Assessments

2.5.1 Shading level

Shading was quantified on the basis of photosynthetically active radiation (PAR) - the spectrum of solar radiation with a wavelength between 400 and 700 nanometers (nm). By adapting the method of Ernesto Méndez, Gliessman and Gilbert (2007), measurements were carried out from 12 p.m. to 1 p.m., namely the hours of greatest incidence of solar radiation, without the presence of clouds, on April 10, 2020, using an AccuPAR® 8.0 ceptometer (Decagon, Inc.). Data were collected above the crown of the coffee tree, at the four cardinal points, in a total of four measurements per point. During the whole period, PAR was measured on the track on the north face of the plot using an external Licor® sensor, previously calibrated with the ceptometer and fitted to a Hobo Station (*Onset Compute Corporation*, Bourne, MA, USA). Thus, the external PAR can be measured at the exact moment when the internal PAR is measured. To calculate shade percentage, the following Equation (1) was used:

$$\%Shade = \frac{(external\ PAR - internal\ PAR)*100}{External\ PAR} \quad (1)$$

2.5.2 Dry biomass of coffee field

The above ground dry biomass (AGB) of each coffee tree was calculated by adding the dry biomass of its orthotropic branches. The volumetric equation developed by Andrade et al. (2018) was used for coffee trees under shade and under full sun. It is based on the diameter of the trunk at 0.15 m above the ground (D_{15}), measured in meters. Their equation was formulated to determine coffee dry biomass in kilograms (kg), with the following Equation (2):

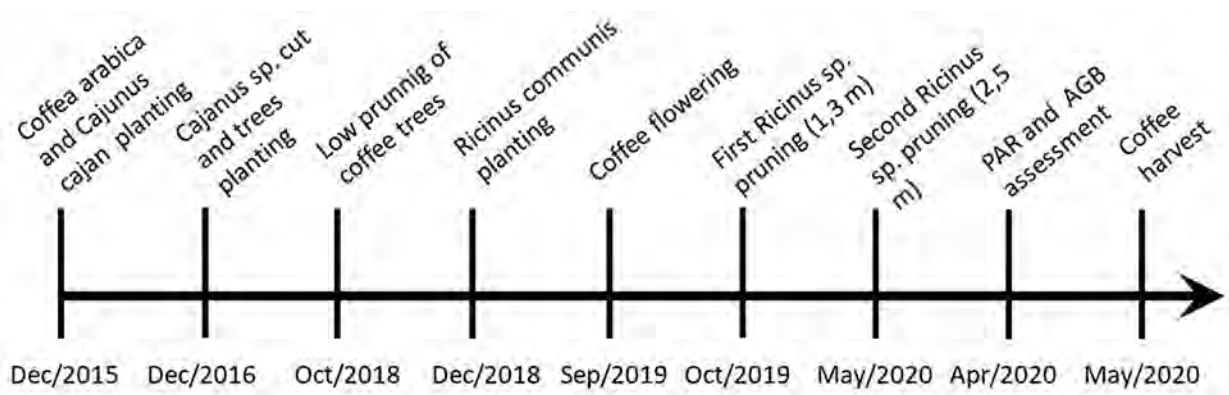

Figure 3: Chronological order (month and year) of the main stages of implementation, management and assessment of the AFS studied, located in Poços de Caldas/ MG - Brazil.

Figure 4: Aerial photography of the AFS studied, located in Poços de Caldas/ MG – Brazil. Illustration of the study distances, from the north face to the interior of the agroforestry system (D1= 1m, D2= 4m, D3= 7m, D4=10m).

$$AGB(kg) = 0.36 - 0.18 * D_{15} + 0.08D_{15}^2 \quad (2)$$

2.5.3 Total fruit volume

The coffee fruits were harvested in the second half of May 2020, at this moment all coffee plants had 4 years and was the first harvest after de coffee low pruning. All fruits (unripe fruits, cherries and dried fruits) were collected from the same previously sampled specimens to determine PAR. Fruit production (Total) was calculated in volume unit, and data were presented as L plant^{-1}.

2.5.4 Percentage of dried fruits

After determination of fruit volume, dried fruits, unripe fruits and cherries were separated by density. For each coffee tree, dry fruit volume (D) was determined and dry fruit percentage was calculated using the following Equation (3):

$$\%Dried = \frac{D*100}{Total} \quad (3)$$

2.6 Statistical analysis

The mean values of the variables coffee dry biomass (AGB), fruit volume (Total), dry fruit percentage (%Dried), incident photosynthetically active radiation (%PAR) and shade percentage (%Shade), on the basis of distances from northern edge of the coffee plot, underwent the Mann-Whitney test. The influence of the variables "Distance", "%Shade", "Total" and "AGB" on dry fruit percentage and, consequently, on fruit ripening, was determined by linear regressions, and the significance levels (p) and coefficient of determination (R^2) were also determined. Finally, the variables underwent multivariate principal component analysis (PCA) to determine the correlations and behavior of each study coffee tree. All analyses were performed in the PAST software, according to the method of Hamer, Harper and Ryan (2001).

3 RESULTS

As shown by data on water balance (Figure 1), the study period (August 2019 to June 2020) can be considered as a year with reduced water availability. Water deficit for the 2018 agricultural year was only compensated for in mid-December 2019, three months after the start of the rainy season, and the amount of water stored in the soil decreased in mid-April, one month before the historical average of the region.

The increase in distances from the sunniest edge (north face) to the interior of the AFS provided higher shading rates. The coffee trees located at D1 (1m away from the sunniest edge, north face, towards the interior of the AFS) had, on average, 5% shade, while the trees at D4 (10 m away from the sunniest edge, north face, towards the interior of the AFS) had approximately 80% shade. However, the shade percentage values of coffee trees at D2 (4 m away from the sunniest edge, north face, towards the interior of the AFS) and D3 (7 m away from the sunniest edge, north face, towards the interior of the AFS) did not differ between each other, showing 70% shade (Figure 5a).

Coffee trees at distance D1 had, at harvest time, 90% of dry fruits while those located at distance D4, only 25% (Figure 5b).

The incident photosynthetically active radiation (PAR) on coffee trees at D1 was 1915 μmol m^{-2}s^{-1}, close to full sun radiation, 2050 μmol m^{-2} s^{-1}. At D2 and D3, the values were similar, about 550 μmol m^{-2} s^{-1}, a higher value than that of D4, the most shaded distance, with 400 μmol m^{-2} s^{-1} (Figure 5c).

The average volumes of fruits of the coffee trees located at D1 and D2 were similar, approximately 1.8 L plant^{-1}, but lower than those located at D3 and D4, which did not differ from each other: 4 L plant^{-1} (Figure 5d).

Dry biomass of coffee trees at D4, 330 g plant^{-1}, was higher than that of coffee trees located at other distances, which did not differ from one another, 300 g plant $^{-1}$ (Figure 6e).

The linear regressions between percentage of dry fruits (%Dried) and the other variables (Distance), (Total), (Shade %) and (AGB) were significant ($p<0.005$) (Figure 6). The variable that best explained the variation in the percentage of dry fruits was distance, with a coefficient of determination of 0.81 (Figure 6a), followed by total fruit volume, with R^2= 0.60 (Figure 6b) and shade percentage, with R^2= 0.50 (Figure 6c). Dry biomass of coffee trees, although significant, had a low coefficient of determination (R^2= 0.30 (Figure 6d).

PCA analysis (Figure 7) showed that the response of the coffee trees at each distance formed clear groups, especially for individuals located at D1 and D2. The highest percentage of response was found on the x axis of component 1, with 74%, showing that the variables total fruit volume (Total), shading level (%Shade) and distance from the AFS edge (Distance) were positively correlated between them but negatively correlated with the variable dry fruit percentage (%Dried). The high negative correlation between (%Dried) and (Distance) is represented by the angle of approximately 180º between the arrows. For coffee dry biomass (AGB), there was a low correlation with the other variables, as its arrows form angles close to 90°. In addition, its greatest variation was found on the y axis of component 2, which explains 14% of the results, indicating low variation between the analyzed specimens.

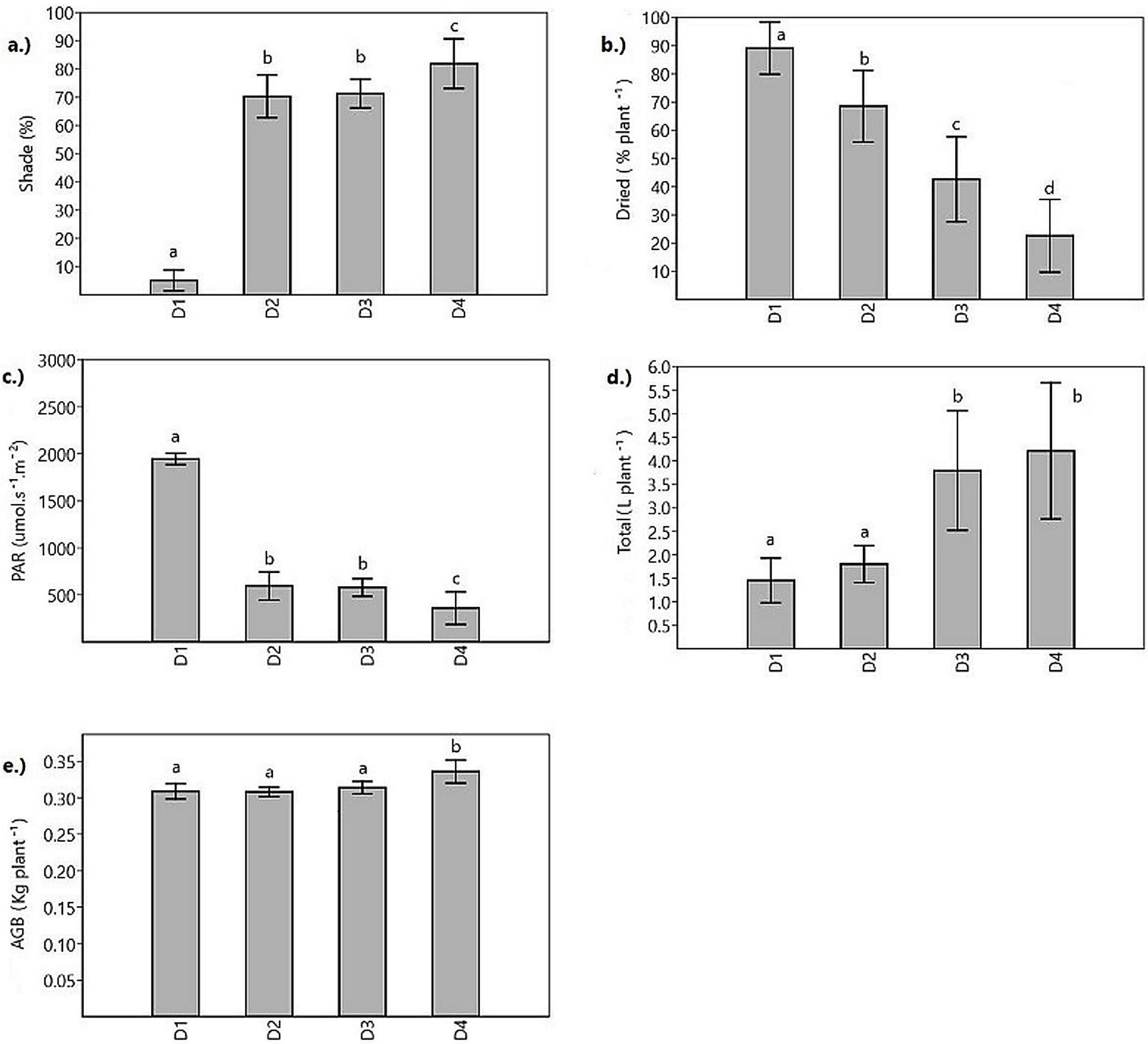

Figure 5: Mean values (bars) and standard deviation (lines) and their significance by the Mann-Whitney test (letters) for each distance from the north edge (D1= 1m, D2= 4m, D3= 7m, D4=10m) of the following variables, quantified in the AFS studied, located in Poços de Caldas/ MG - Brazil: a.)= level of shading, b.)= percentage of fruits harvested at the dry stage, c.)= incidence of PAR inside the agroecosystem, d.)= volume of fruits harvested at all stages of physiological ripening, and .e)= coffee dry biomass.

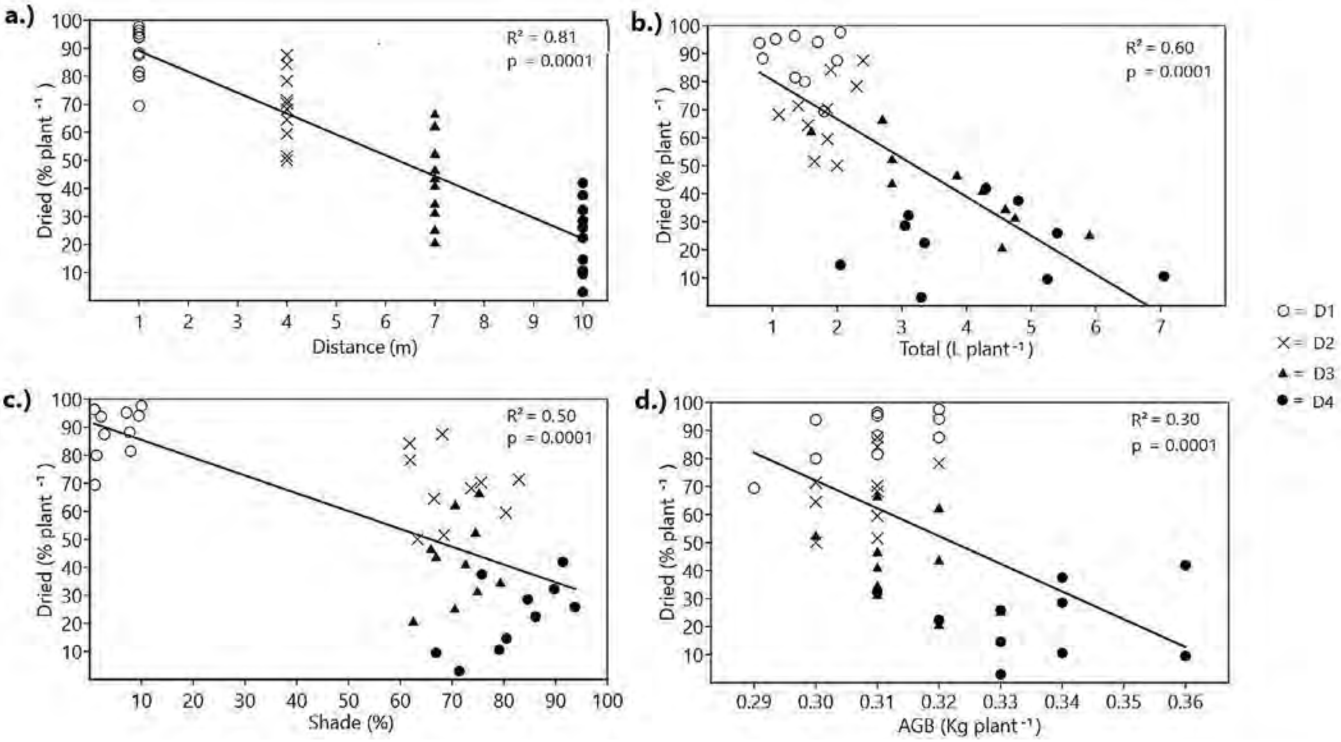

Figure 6: Graphic representation of linear regressions between variables, their levels of statistical significance (p-value) and coefficient of determination (R^2): a.) dry fruit percentage (%Dried) and distance from the AFS edge (Distance), b.) dry fruit percentage (%Dried) and total fruit volume (Total), c.) dry fruit percentage (Dry %) and shading level (Shade%), d.) dry fruit percentage (%Dried) and coffee dry biomass (AGB).

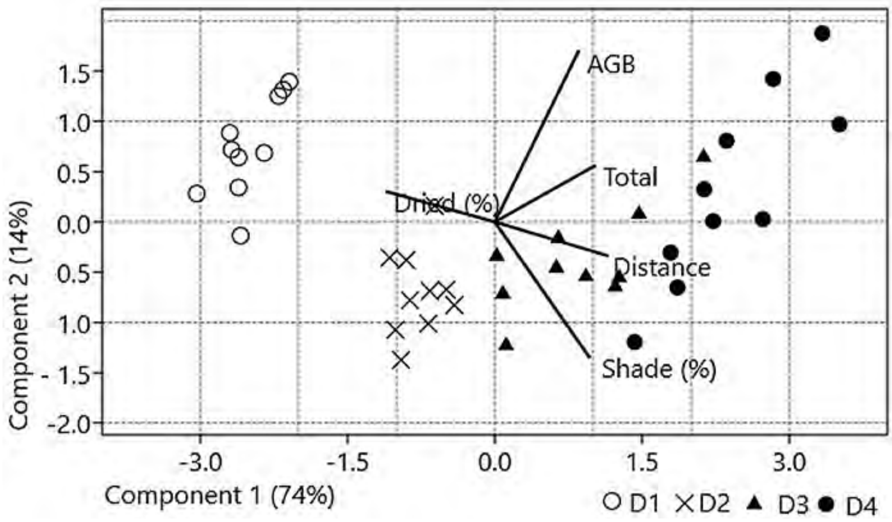

Figure 7: Multivariate principal component analysis. Plotting of the 40 sampled points, on the basis of the distance from the border of the north face D1=1 m, D2=4m, D3= 7 m, D4= 10 m, in four quadrants showing the ratio of magnitude of the quantified variables, Distance= Distance from the edge of AFS, Dried (%) = Percentage of fruits harvested at the dry stage, Total = Volume of fruits harvested at all stages of physiological ripening, Shade (%) = Shading level, AGB = Coffee dry biomass).

Therefore, the individuals located at D1, followed by those at D2, had the lowest shading rates, presented higher dry fruit percentage and lower total fruit volume. On the other hand, those at D3 and D4, i.e., the ones with the highest shading rates, had higher fruit volumes and a lower dry fruit percentage.

4 DISCUSSION

PAR assessments were carried out at the transition from autumn to winter. At that time, in the southern hemisphere, the sun has the lowest declination relative to the horizon, approaching the north cardinal direction. For the study latitude, the sun is approximately 50° closer to the horizon in the winter solstice than in the summer solstice; therefore, in this period, the highest shading rates occur, mainly on the south face (Bedaque; Bretones, 2016). Therefore, the greater shading at the distances located inside the plot can be explained by the sun's path, by the face of the plot (south) and planting direction of coffee and *Ricinus spp*. plants (north-south).

The low inclination of the sun, facing north, not only leads to increased shade, but also contributed to the sum of the shade of the canopy components when walking southwards, that is, the coffee trees at D4, the furthest south, are shaded by coffee and *Ricinus spp*. plants located at D3, D2 and D1. Another effect that may have contributed to the higher shade rates at D4 is the proximity effect with the row of banana trees; however, this effect was minimized because the row was further south than the coffee trees at D4 (Figure 4).

The *Ricinus spp.* canopy was the main responsible for the shading of the coffee trees, in addition to the banana trees (mainly for distances D4) and the self-shading of the coffee trees. Few arboreal individuals, which will form the future canopy, were tall enough o shade the coffee trees, therefore, their influence was not considered in the discussion.

The coffee trees located at D1, by the edge of the AFS, were hardly influenced by shading from the *Ricinus spp*. canopy. After all, they are located towards the north; therefore, they had the highest incidence rates of photosynthetically active radiation (PAR), similar to the value quantified under full sun. The other coffee trees had high shading rates, around 70% for the coffee trees at D2 and D3 and 80% of shade for those at D4.

The quantification of the incident photosynthetically active radiation in agroforestry enables an analysis of both light intensity and quality of incident radiation. PAR under full sun is approximately 2,000 μmol $m^{-2}s^{-1}$ (Taiz et al., 2017) and light saturation of coffee leaves occurs between the lower limit of 300 μmol $m^{-2}s^{-1}$ and the upper limit of than 700 μmol $m^{-2}s^{-1}$ (DaMatta, 2004). Therefore, despite the high levels of shading found in this study, the incidence of photosynthetically active radiation in the coffee trees, at the time of assessment, remained within the limit at D2 and D3 (approximately 550 μmol $m^{-2}s^{-1}$) and at D4 (400 μmol $m^{-2}s^{-1}$).

For the analysis of total fruit volume, it is worth noting all plagiotropic branches and flower buds responsible for this production had developed in the summer of 2018-2019, under full sun at all distances. And it was the first year of production after the coffee trees had been pruned, which is when the plants are expected to have maximum productive response. At the time of flowering (August 2019), the *Ricinus spp*. canopy had not yet been fully established. Thus, it was a less influential factor for the flowering of the coffee trees. In addition, pruning carried out for the purposes of training (October 2019) and to admit a greater amount of light (March 2020) in the temporary canopy of the *Ricinus spp*. plants, may have allowed enough active photosynthetic radiation to enter at the fruit set stage.

In fact, the shade variable (Shade%) showed a reduced correlation with fruit volume (R^2 of 0.30); therefore, it can hardly explain the variation in the volume of fruits produced.

Ripening of the yellow Bourbon variety is registered and classified by the Instituto Agronômico de Campinas (IAC) as earlier ripening (Fazouli et al., 2005). In this test, during the fruit ripening stage (April to May), the *Ricinus spp*. canopy was already well established; therefore, it affected the ripening speed of the coffee fruits. It was evident that the greater the shading, the slower the ripening. This behavior of the coffee tree has also been reported by other authors. Vaast et al. (2006) found a one-month reduction for the beginning of fruit ripening in shaded coffee trees (45% of artificially generated shade) in comparison to full sun conditions in the same production unit. Ricci, Costa and De Oliveira (2010), when studying coffee trees under full sun and shaded by intercropping of *Musa sp*. and *Erythrina verna* Vell., found 72% more dry seeds in coffee trees under full sun, at the beginning of the harvest.

According to Pezzopane et al. (2003), air temperature is considered to be the most relevant climate variable for coffee fruit ripening; however, as found by Petek, Sera and Fonseca (2009), a reduction by 100 mm in cumulative annual precipitation may require less time - a reduction between 70 and 140 degree days - for coffee fruit ripening to be completed. Therefore, the physiological process of coffee ripening is especially affected by air temperature and water availability (Petek; Sera; Fonseca, 2009).

As found for water balance, during the period of the experiment (Figure 2), the coffee trees were under water stress during the time of flowering and seed ripening. Decreased precipitation and the beginning of water deficit in mid-March 2020, as well as the average temperatures (above 20 °C) until mid-April, helped to increase fruit ripening speed.

Muschler (2001) attributed the longest ripening time of coffee fruits in shaded systems to the reduction in daily average temperature. The air temperature was not measures in the present study, however, probably, higher air temperature values would be found at distances closer to the sunniest edge (north face), where the coffee trees had more dried fruits. On the other hand, at the shaded distances, there could have been greater competition for water between coffee trees and *Ricinus spp.*, thus accelerating fruit ripening; however, this did not occur.

Ricinus spp. crops are considered to demand low amounts of water. The phase of greater water need by *Ricinus spp*. plants is during reproductive development, at the development stage of the second bunch and during the ripening of the first bunch (Dias et al., 2015). Therefore, it can be inferred that there was no competition for water between the coffee trees and the temporary canopy, owing both to the physiological characteristics of the *Ricinus spp.* trees and to the pruning management performed previously.

For coffee production, the design and management of shading in multistrata agroforests have different purposes, particularly those of providing adequate levels of solar radiation and increasing natural fertility (Schnabel et al., 2018). However, stratification design can also be planned for pest and disease control, as cited by (Staver et al., 2001). In fact, the choice of the correct tree species and light pruning are believed to be the reasons for successful organic management of coffee plantations with shade trees compared to conventional ones (Schnabel et al., 2018).

The distances from the sunny edge of the AFS was the variable that best explained the responses of the other variables; after all, different environmental factors may be linked to it. For example, a possible variation in soil fertility and moisture owing to the distance from the track. Two main factors can be assumed to be influential: the greater solar irradiance and temperatures at the edge of the AFS owing to its proximity to the border (4-meter-wide open area) and greater humidity and fertility inside the AFS, close to the banana tree row. Banana trees are usually used in coffee agroforestry systems to improve microclimatic conditioning and increase soil fertility (Ricci; Costa; De Oliveira, 2010). In case of increased fertility close to the row of banana trees, the dry biomass of coffee trees located at D4 may also have increased.

On the other hand, *Ricinus spp*. plants shading, especially during the last agricultural year, may have contributed to an increase in coffee dry biomass. Coltri et al. (2015), when developing equations to predict leaf area index (LAI) and dry biomass of shaded and unshaded coffee trees in southern Minas Gerais, found that shaded coffee trees tend to have greater dry biomass. They found that most of the carbon content is stored in the trunk and branches, and the greater height of shaded coffee trees provides greater biomass accumulation, even with smaller amounts of carbon in the leaves. In this experiment, the volumetric equation was based on the trunk diameter at 15 cm from the ground, considered by Coltri et al. (2015) and by Andrade et al. (2018) as the most determinant, and the most shaded distances were those with the largest diameter, hence with the greatest dry biomass.

Understanding the dynamics of ripening coffee fruits is necessary for planning the harvest better. Based on such insights, arrangements can be made for agroforestry systems by combining the use of coffee cultivars with different ripening times with light intensity management (linked to succession management in agroforestry systems), in order to plan harvesting activities and produce the greatest number of fruits at the cherry stage.

5 CONCLUSION

The coffee fields located at 1, 4, 7 and 10 meters from the northern edge of the agroforest received photosynthetically active radiation at different intensities. The greater the distances towards the south, the greater was the shading level, due to sum of the *Ricinus spp.* shadows, the self-shading of the coffee trees and the banana trees shadows (mainly for distances D4). Shading percentage was negatively correlated with number of dry fruits. However, other factors can explain this phenomenon, and the sum of them is represented by the variable distance. Despite the high levels of shading, the amount of photosynthetically active radiation was satisfactory: the most shaded coffee trees produced the largest fruit volume. It can be concluded that the design and management of the study multistrata agroforest contributed to these results. The influence of the temporary canopy of the *Ricinus spp.* on the shading of the coffee trees was evidenced. The increase in shade levels may have contributed to a reduction in air temperature and an increase in soil moisture, contributing to slower ripening of the coffee fruits. The coffee trees in D4 showed higher biomass, a possible increase in soil fertility due to the proximity to the banana row may have contributed to this result. These unassessed factors are of great importance and should be considered in future studies.

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7 AUTHOR CONTRIBUTION

PHML wrote the manuscript and conducted the experiment; REO co-authored the manuscript and supervised the experiment; ADB supervised the statistical analysis, interpretation and analysis of results; GB assisted in conducting the experiment, prepared the water balance and revised the final version of the manuscript; AF co-authored the manuscript, supervised the experiment, reviewed and approved the final version of the manuscript.

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