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Microclimate in coffee plantation grown under grevillea trees shading

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ABSTRACT. Measurements of solar global radiation, wind speed, temperature and relative humidity of air were made in a coffee plantation (*Coffea Arabica* L. variety Icatu Vermelho- IAC 4045), grown under conditions of shading levels caused by grevillea trees (*Grevillea robusta*) in Mococa-SP region (21° 28' S, 47° 01' W, altitude 665m), between January and December 2005, aiming to show the effects of shading crop system on the microclimate. The results showed that there was a reduction of about 26% of solar global radiation in the shaded systems, with a monthly variation of 24-30%. It has been highlighted some differences in the transmittance of global radiation in the shaded coffee trees due to the spatial variation of grevillea canopy. There was a reduction of about 35% in the five days-averaged wind speed in the shaded system that also presented reduced maximum air temperature and a reduction in the vapor pressure deficit during day-light period, especially in the point sampled near to the grevillea trees.

Keywords: shading system, *Coffea arabica*, solar radiation, microclimate.

RESUMO. Microclima de café arborizado com grevílea. Medições de radiação solar global, velocidade do vento, temperatura e umidade relativa do ar, foram realizadas em um cafezal (*Coffea arabica* L.) cv. Icatu Vermelho IAC 4045, cultivado a pleno sol e arborizado com grevílea (*Grevillea robusta*), no município de Mococa – SP (21° 28' S, 47° 01' W, altitude 665 m) entre janeiro e dezembro de 2005, com o objetivo de apresentar os efeitos do cultivo arborizado no microclima. Os resultados obtidos mostraram que houve atenuação média dos valores de radiação solar global, em cultivo de café arborizado, em 26%, com variação mensal de 24 a 30%. Pela descontinuidade da cobertura das árvores de grevílea, foi verificada diferença de transmissão da radiação solar em diferentes pontos do sistema arborizado. Foi verificada ainda redução média de 35% nas médias quinquidiais da velocidade do vento no cultivo arborizado em relação ao cultivo a pleno sol. O cultivo arborizado promoveu redução na temperatura máxima do ar e no déficit de saturação de vapor no período diurno, sendo essas reduções mais evidentes no ponto amostral próximo à árvore de grevílea.

Palavras-chave: arborização, *Coffea arabica*, radiação solar, microclima.

Introduction

The use of shading system in coffee aims to minimize the exposition of plants to climatic risks like frosts, excess of radiation, winds and high temperatures, which contributes to increase the sustainability of the crop (VAAST et al., 2006).

The solar radiation is one of the main modified meteorological elements in the shaded system. Micrometeorological studies made in shaded systems need to focus in this element because it determines the availability of energy for evapotranspiration, air and soil heating and photosynthesis (MONTEITH et al., 1991).

The effect of natural shading on the microclimate of coffee crop in relation to plant development, yield and beverage quality has been studied in several situations (BAGGIO et al., 1997; BARRADAS; FANJUL, 1986; BEER et al., 1998; PEETERS et al., 2003). These works describe the effect of shading in a qualitative approach regarding the kind of the tree utilized and planting density, nevertheless few authors quantify the solar interception. For example, the works of Pezzopane et al. (2003), in a shaded coffee system with green dwarf coconut, of Farfan-Valencia et al. (2003) about shaded system in Colômbia and Pezzopane et al. (2005) about shaded coffee system with dwarf 'Prata' banana.

Various authors observed the variation of other meteorological elements in shaded coffee system in different regions of Brazil and other countries, such as the papers of Barradas and Fanjul (1986) about coffee agroforestry system in Mexico, an example of coffee shaded with bracatinga at Londrina, Paraná State, Brazil (CARAMORI et al., 1996), a coffee shaded with dwarf coconut at Garça, São Paulo State (PEZZOPANE et al., 2003) and a shaded coffee system with dwarf 'Prata' banana (PEZZOPANE et al., 2007). These researches make clear the great differences in wind speed, soil conditions and vapor pressure deficit between the shaded and unshaded system. These differences were related to temporal and spatial variability and depend on the kind and planting density of tree utilized for shading.

This paper aims to compare the effects of coffee shaded with grevilea trees with unshaded system at Mococa, São Paulo State, a traditional coffee region in Brazil.

Material and methods

Microclimatical observations were realized from January up to December of 2005 in coffee (*Coffea arabica* L.) cv. Icatu Vermelho IAC 4045 grafted over cv. Apoatã IAC 2258 of 6 years old, in unshaded system and shaded with grevillea tree (*Grevillea robusta* A. Cunn. ex R. Br.), in Mococa, São Paulo State (21° 28' S, 47° 01' W, altitude 665 m).

The spacing of coffee trees were 4 x 1 m and the plants had approximately 1.8 m heigh. The grevillea trees had a spacing of 16 x 16 m with 7 m height, and the plot production had a spacing of 40 x 40 m.

The microclimatic characterization was made by measuring several parameters: global solar radiation was measured by means of tube solarimeters (TSL, Delta T Devices) installed above the coffee canopy (2.0 m); air temperature and relative humidity were determined by psicrometric system (Vaisala, HMP 45C) protected by a micrometeorological cover consisting of 12 plastic plates (RM YOUNG, Gill) installed at the top of the coffee canopy (2.0 m); and for wind velocity we used anemometers (RM YOUNG, 03001-L) installed at 2 m height.

The scheme showing the arrangement of sensors in the shaded plot can be seen in Figure 1. The sampling of global solar radiation (points 1 to 4) was made following Wallace (1996) and Pezzopane et al. (2005) who studied an arborization system using grevillea tree with corn and coffee, respectively. The sampling of air temperature, air relative humidity and wind speed were taken in two points of the shaded system, one near the grevillea tree (Point 1) and other at the central part of the plot (Point 3).

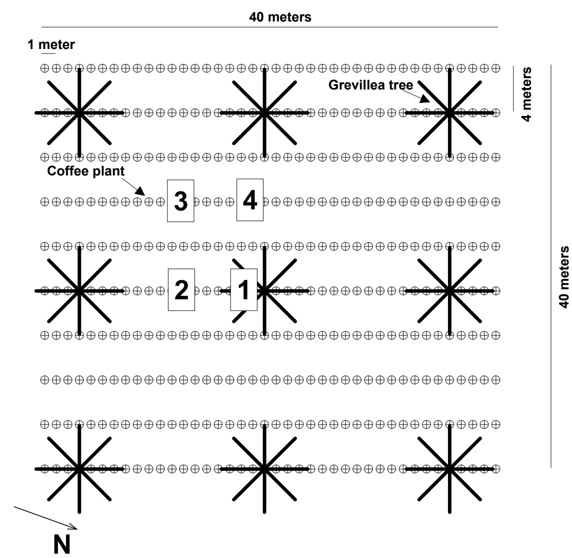

Figure 1. The installation scheme of the sensors at the shaded plot (Points 1 to 4).

The sensors were connected to a datalogger (CR10X, Campbell Scientific Inc.) programmed to take readings every 20 seconds with averages at each 15 minutes and a integralization of daily global solar radiation (MJ m^{-2} day^{-1}).

Micrometeorological evaluations were made aiming the comparison of unshaded system in which the sensors of air temperature, relative humidity and wind speed were installed at the same height of the shaded system.

The standard meteorological data system of the Polo APTA Nordeste Paulista Center, in Mococa, was used to measure the global solar radiation for unshaded system at approximately 500 m away from the experimental plot.

The discussion about the atmospheric humidity was complemented by the calculation of the saturation and actual pressure vapor and vapor deficit pressure following the equations proposed by Pereira et al. (1997).

The effect of grevillea tree in the solar radiation available to the coffee canopy for monthly and hourly (7 to 18 hours) scales for two points samples were evaluated using surface graphics interpolated with kriging method.

Results and discussion

The grevillea trees result in reduction of global solar radiation (GR) to the coffee canopy. The values of shaded GR showed significant reduction in all sampling points (1 to 4) inside the shaded system and the relationship between shaded GR and unshaded GR were always lower than one. The transmission was more severely affected near the grevillea tree (sampling point 1), varying between 20 and 29%. The reduction at the points 2, 3 and 4 were lower than 20% (Table 1).

Table 1. Monthly average global solar radiation (GR) (MJ m^{-2} day^{-1}) and at standard meteorological station and average transmissivity of GR at different sampling points in coffee shaded with grevillea tree, in 2005 at Mococa, São Paulo State.

Month	GR (MJ m^{-2} dia^{-1}) Standard Meteorologial Station	Transmissivity of GR at different sampling points in coffee shaded				
		P1	P2	P3	P4	Average*
January	17.8	0.23	0.90	0.92	0.92	0.74
February	23.5	0.20	0.91	0.95	0.93	0.75
March	19.3	0.29	0.91	0.93	0.92	0.76
April	18.4	0.25	0.91	0.90	0.84	0.72
May	15.8	0.25	0.90	0.88	0.83	0.72
June	14.9	0.24	0.88	0.88	0.89	0.72
July	14.8	0.25	0.88	0.85	0.84	0.70
August	19.2	0.24	0.89	0.88	0.89	0.73
September	16.6	0.27	0.90	0.93	0.93	0.76
October	20.1	0.26	0.90	0.94	0.92	0.75
November	19.7	0.28	0.86	0.94	0.89	0.74
December	18.6	0.29	0.85	0.95	0.84	0.73

*Average of sampling points in the arborized plot.

The monthly average GR transmission had a variation from 70% up to 76%. The greater reductions were from April up to August and lower in spring and summer. These results were similar to others obtained from shaded systems in São Paulo State, Brazil. Pezzopane et al. (2003, 2005) and Pezzopane et al. (2005) observed that the greater reduction in GR transmissivity occurred during autumn and winter, when the zenithal angle is greater increasing the influence of trees over the coffee plantation. Other fact that contributed for this tendency is related to the cloudy days during the summer that increase the diffuse radiation, multidirectional, increasing the transmissivity in the system.

The average monthly and hourly GR of two sampling plots of the shaded system can be seen in Figure 2A. The GR ranged from 100 W m^{-2} in the first hours of morning to 800 W m^{-2} at noon mainly from February to October.

Analyzing the transmission of GR at the central sampling point in the shaded system (Point 1) (Figure 2B) we could observe that greater transmissions occurred at morning, up to 9 a.m., and in the afternoon, after 4 p.m. Between 10 a.m. and 3 p.m. occurred a decrease in transmission - the values were inferior to 20% during this period for most part of the year, which indicates a shielding effect of the grevillea tree leaves onto the coffee plants.

The transmission was higher at the central sample point (Point 3) (Figure 2C) keeping above 90% during the study. After 3 p.m., during autumn and winter occurred a decrease in the transmission mainly from May to August due to the effect of the grevillea tree near the measurement. The larger the diameter of the canopy and smaller the spacing among the shading trees the lower the transmissivity at the central point of the shaded plot.

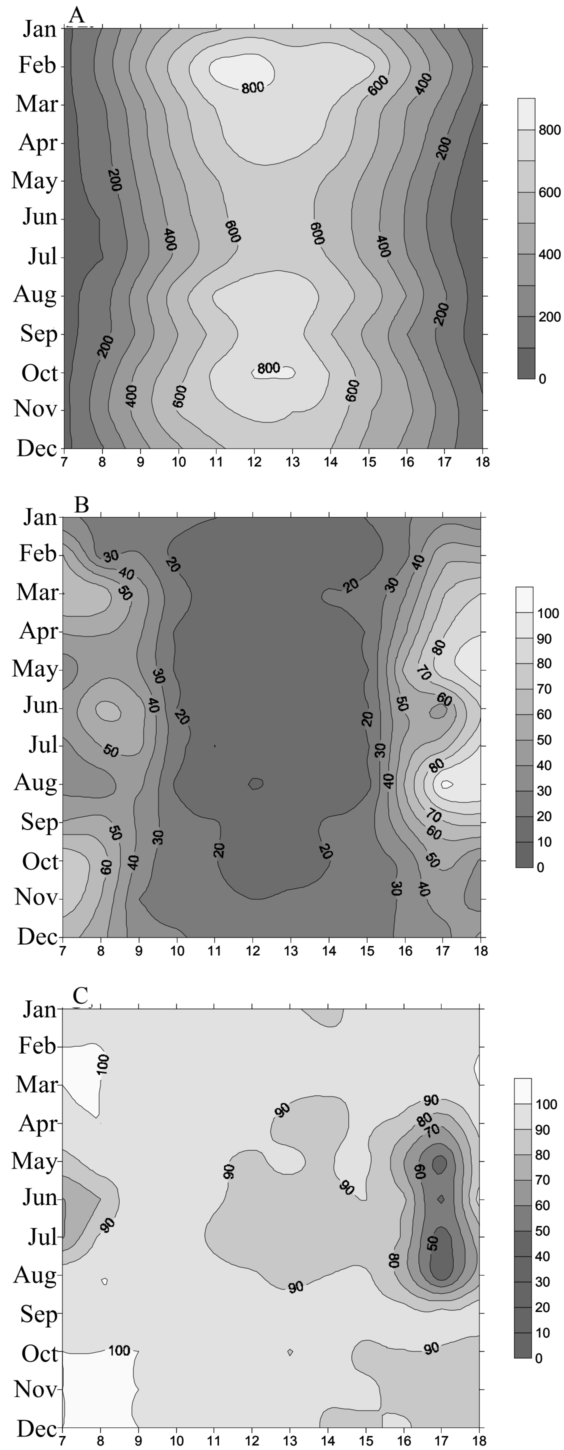

Figure 2. Hourly global solar radiation (W m^{-2}) (A), hourly transmission of global solar radiation at point 1 (B) and hourly transmission of global solar radiation at point 3 (C) at coffee unshaded and shaded with grevillea trees from January to December of 2005, at Mococa, São Paulo State.

The comparison of the daily GR (unshaded system) and the transmission at different points in the shaded plot (average of the sampling points) can be seen in Figure 3. The angular coefficient (0.74) indicates an average reduction of 26% in transmissivity promoted by the grevillea trees. Camargo and Pereira (1994) related that shading trees of shaded coffee system in tropical regions should cover about 20% of the surface, and the excess of shading can be disadvantageous to coffee production (DAMATTA, 2004).

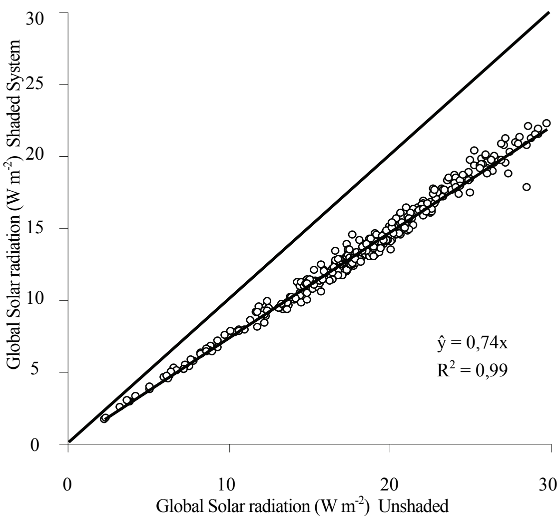

Figure 3. Comparison of global solar radiation (MJ m^{-2} day^{-1}) in a unshaded and shaded system with grevillea tree (average of sampling points) from January to December of 2005 at Mococa, São Paulo State.

The average wind speed for unshaded and shaded coffee production for different seasons and the results of t-test are shown in the Table 2.

Table 2. Seasonal average wind speed (m s^{-1}) and values and t-test at 1% of probability in unshaded and shaded coffee cultivation measured at different sampling points at Mococa, Sao Paulo State.

Season	Unshaded	Shaded system		t value		
		P1	P3	PS –P1	PS - P3	P1 - P3
			Wind Speed (m s^{-1})			
Springer	0.83	0.34	0.68	11.10 **	2.72 **	8.09 **
Summer	0.73	0.45	0.63	7.36 **	2.37 **	5.04 **
Autumn	0.71	0.26	0.59	12.91 **	2.97 **	12.56 **
Winter	0.90	0.32	0.80	10.26 **	1.48 *	10.30 **

* = significant at 5% of probability; ** = significant at 1% of probability.

The differences in the values of the average wind speed were significant by t-test at 1% of probability among the sampling points in the shaded system in all seasons and between the different cultivation systems. In relation to the spatial variability in the arborized system, the lower values, for all seasons, were found at the sampling point 1, near the grevillea tree.

The five days base average of wind speed for both systems are presented in Figure 4.

The reduction of the wind speed promoted by the grevillea tree during all experiment ranged from 15 to 60% in relation to the unshaded system (Figure 4), with an annual average of 35%. Camargo and Pereira (1994), concluded that one of the most beneficial effects of shaded coffee systems in the Brazil conditions is the reduction of wind speed, what could cause physical damages to the leaves and reduce the plant growth (CARAMORI et al., 1986).

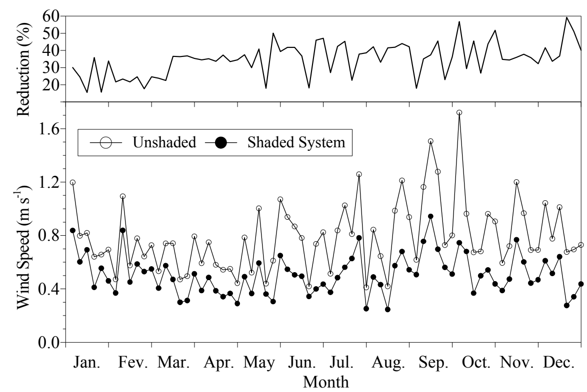

Figure 4. Five-day base averages of Wind speed (m s^{-1}) in unshaded coffee system and shaded with grevillea tree, at Mococa, São Paulo State.

The average maximum and minimum air temperature, besides vapor pressure deficit for the period of 10 a.m. to 2 p.m. for unshaded and shaded system is presented at the Table 3.

Table 3. Average maximum and minimum temperature (°C), vapor pressure deficit and t-test for average comparison for unshaded system and shaded with grevillea tree, at Mococa, São Paulo State.

Season	Unshaded	Shaded system		t value		
		P1	P3			P1
			Maximum temperature (°C)			
Springer	31.2	30.0	31.2	2.08 **	0.13 ns	2.26 *
Summer	32.7	31.4	32.8	3.1 **	0.28 ns	3.35 **
Autumn	30.4	29.0	30.0	2.52 **	0.76 ns	1.97 *
Winter	29.4	28.2	29.1	1.94 *	0.36 ns	1.55 ns
			Minimum Temperature (°C)			
Springer	18.0	18.0	17.8	1.87 ns	0.17 ns	1.75 ns
Summer	18.9	19.0	18.9	0.28 ns	0.34 ns	0.64 ns
Autumn	15.9	15.8	15.7	0.35 ns	0.40 ns	0.07 ns
Winter	13.4	13.6	13.5	0.24 ns	0.19 ns	0.04 ns
			Vapor pressure deficit between 10-14 hours (kPa)			
Springer	1.88	1.71	1.85	1.36 ns	0.27 ns	1.09 ns
Summer	1.91	1.67	1.85	2.17 *	0.53 ns	1.58 ns
Autumn	1.91	1.62	1.81	2.72 **	0.85 ns	2.08 *
Winter	2.08	1.83	2.03	2.03 *	0.40 ns	1.62 ns

ns = not significant; * = significant at 5% of probability; ** = significant at 1% of probability.

The grevillea trees in the shaded system promoted a reduction of maximum air temperature in relation to the unshaded system (Table 3). The seasonal average values of the maximum air temperature obtained at sampling point 1 (near the grevillea trees) showed significant differences by the t-test when compared to the unshaded system for spring, summer and autumn with differences always higher than 1°C. The autumn condition results in an average difference of 1.4°C higher than the unshaded system.

There was a spatial variation of maximum air temperature in the shaded system, for example in the sampling point 3 (central point) the average values were always higher than the sampling point 1 in the shaded system, showing significant differences by t-test for spring, summer and autumn. During the winter occurred the greater radiation interception in the beginning of the afternoon (Figure 2) when decrease the difference of the air temperature among the measurements points. The spatial variability of air temperature during the day-light period also was found by Pezzopane et al. (2007) in coffee shaded with banana plants.

Although the maximum air temperature in the shaded system was higher in relation to the sampling point 3 of the shaded system, these differences were not significant. Only in autumn occurred interceptions higher than 10% of global solar radiation and during this period there were more differences between the maximum air temperature at the point 3 in the unshaded and shaded system. Same results were described by Brenner (1996) in arborized conditions and Pezzopane et al. (2003) about a coffee shaded with green dwarf coconut.

Analyzing the variation of minimal temperature in the systems, the averages throughout the seasons of the year were similar between them and no significant differences were found. Only during the winter the averages were 0.2ºC higher for arborized coffee in comparison to the unshaded coffee system.

Analyzing the vapor pressure deficit between 10 a.m. and 2 p.m., period of greater water demand, it can be verified that the shaded system showed smaller values than the unshaded system. At point 1 of the shaded system those differences were significant in relation to the unshaded system during the summer, autumn and winter. Similar values were found by Barradas and Fanjul (1986) in the characterization of agroforestry system in México. The authors attributed those results to the minimal values of temperatures of the day, caused by the interception of incident radiation over the shaded coffee trees, fact also verified in this paper. DaMatta (2004) related that the coffee stomata are highly sensible to relative humidity drop. In this sense, according to that author, that reduction of vapor pressure deficit (which generally occurs in arborized systems of coffee) seems to contribute to the maximization of water use efficiency (photosynthesis rate per unit of water transpired), through the maintenance of stomatic aperture, making possible a suitable transference of CO_2 to the photosynthesis, without however lose a considerable amount of water by transpiration.

Conclusion

The transmission of solar global radiation in shaded coffee with grevillea was of 74% higher in comparison to the unshaded system, with a monthly variation of 70 to 76%.

Due to the discontinuity in the coverage from grevillea trees, we verified differences on transmission of global radiation at different points of the shaded system, according to the season of the year and the time in which the sample was taken.

There was an average reduction of 35% in the five-day base averages of wind speed in the arborized system in comparison to the unshaded system. The shaded system resulted in reduction of maximum air temperature and deficit of vapor saturation during the day, and it was observed that those reductions were more evident at the sampling point next to the grevillea tree.

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