



Animal thermal comfort indexes in silvopastoral systems with different tree arrangements



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ABSTRACT

This study aimed to assess solar radiation transmission and animal thermal comfort indexes in two silvopastoral systems established with different tree arrangements in a tropical region. This study was conducted between 2014 and 2017 in two silvopastoral systems, one composed by an established *Urochloa* (*syn. Brachiaria*) *decumbens* pasture with Brazilian native trees planted in triple rows spaced 17 m apart, and another by an established *Urochloa* (*syn. Brachiaria*) *brizantha* (Hochst ex A. Rich.) Stapf ‘BRS Piatã’ pasture with *Eucalyptus urograndis* (clone GG100) trees arranged in single rows spaced 15 m apart. In these systems and in a full-sun pasture, photosynthetically active radiation transmission, air temperature, relative humidity, black globe temperature, and wind speed were measured. These variables were used to calculate black globe temperature and humidity index (BGHI) and radiant thermal load (RTL). Higher animal thermal comfort was observed in the silvopastoral systems due to changes in the microclimate induced by the trees; notably, a decrease in solar radiation transmission. Fewer hours of potential animal thermal stress (BGHI > 79) were observed in the silvopastoral systems than under the full-sun conditions, with differences up to 3 h per day. The silvopastoral systems presented lower radiant thermal load than the full-sun pasture with differences up to 22% achieved. The assessed silvopastoral systems may help livestock adapt to climate change, since they achieved the limit of BGHI considered to cause stress to animals following an increase of 2.2 °C in air temperature, compared with full-sun pastures.

1. Introduction

In intertropical zones, livestock are predominantly reared on pastures, an important economic activity in most tropical countries (Parente and Ferreira, 2018). Due to the large climatic differences among tropical biomes, climate is the main factor that determines animal production in this region, as it affects pasture production (Pezzopane, 2016) as by affecting animals (Garcia, 2013; Romanello et al., 2018).

Climate change scenarios provided by the PRECIS (Providing Regional Climate for Impact Studies) Program reveal significant changes in the distribution and amount of precipitation, and increases in the maximum and minimum air temperature in Brazil (Marengo et al., 2009). These scenarios may increase the level of stress to animals, which reduces their production and reproductive efficiency (Pantoja

et al., 2017). Therefore, pastoral systems that reduce negative climate effects on animals are necessary. Silvopastoral systems are attractive alternatives to reduce heat loads and to increase animal thermal comfort. In these systems, trees are integrated with pastures, with significant contributions for livestock sustainability in tropical regions (Paciullo et al., 2011; Broom et al., 2013).

Adopting production systems that attenuate climatic factors can provide more comfort and benefit bovines, both of European and zebu genotypes or crosses of them (Bennett et al., 1985). However, the changing perception of the consumer about food production practices in various parts of the world is very present and noticeable (Drouillard, 2018; Hocquette et al., 2018), which justifies the development of technologies to provide more comfort and welfare to production animals. Although new practices demand higher costs and investments, a considerable proportion of consumers are willing to pay more for food

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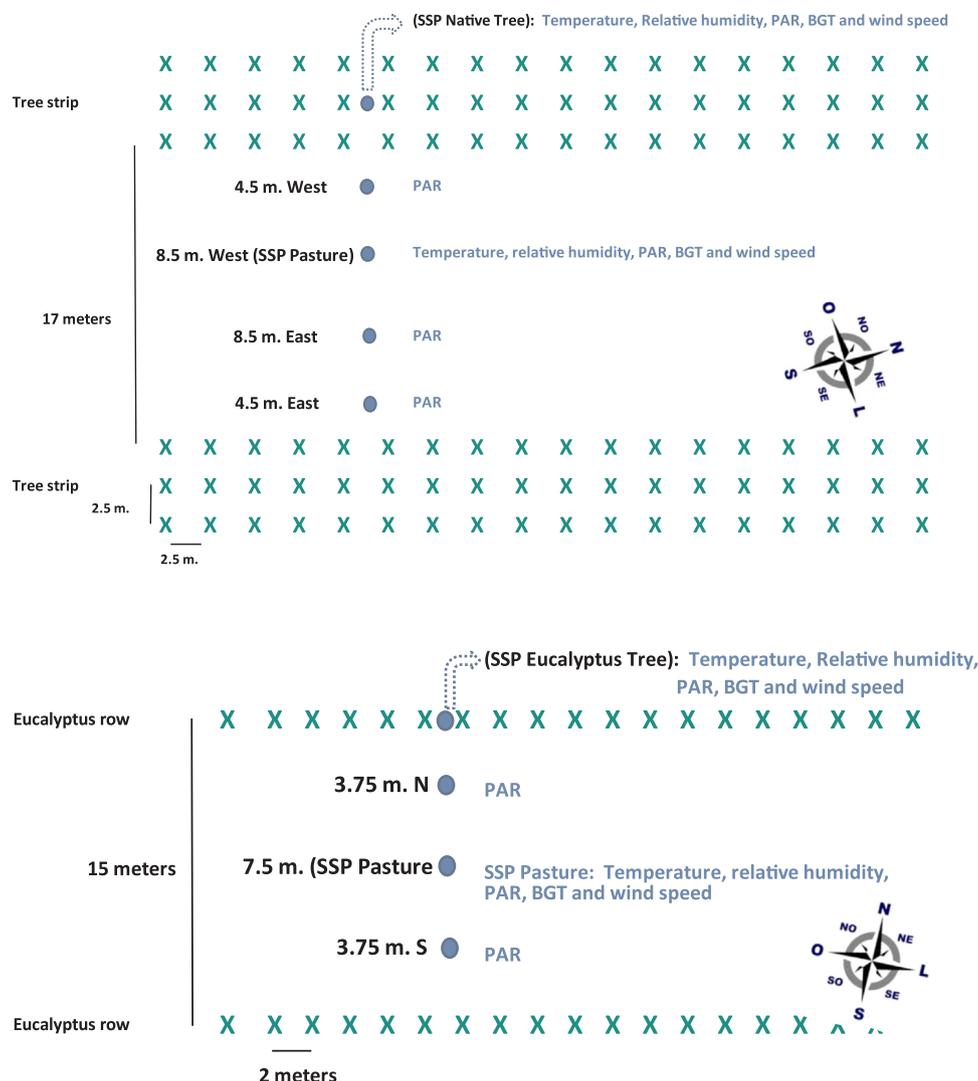


Fig. 1. Schematic representation of the experimental areas with the distribution of the meteorological stations in the silvopastoral systems with Brazilian native trees (above) and with eucalyptus (below). PAR = photosynthetically active radiation; BGT = black globe temperature.

produced with well-defined etic precepts (Frey and Pirscher, 2018) and under conditions that prioritize animal welfare (Sonoda et al., 2018).

In tropical and subtropical regions, several studies have been carried out to estimate animal thermal comfort in silvopastoral systems through microclimatic measurements (Baliscei et al., 2013, Karvatté Jr. et al., 2016, Oliveira et al., 2017), and to evaluate their positive effects on the physiological and productive characteristics of animals (Navarini et al., 2009; Paciullo et al., 2011; Silva et al., 2011, 2014). However, most of these studies calculate thermal comfort indexes in instantaneous events at specific times of the day.

Silvopastoral systems can be implemented using several combinations of tree species, arrangements, and planting densities, resulting in variation in solar radiation transmission by trees in these systems (Silva and Maia, 2013; Pezzopane, 2015), which impacts on other microclimatic characteristics (Silva-Pando et al., 2002; Baliscei et al., 2013), on thermal comfort potential, and on variability within the systems (Karvatté Jr. et al., 2016). Therefore, this study aimed to assess the transmission of solar radiation and indexes of animal thermal comfort in two silvopastoral systems established with different tree arrangements and with tree thinning in a tropical region.

2. Material and methods

This study was conducted in two silvopastoral systems at Embrapa

Pecuária Sudeste in São Carlos, state of São Paulo, Brazil (21° 57'S, 47° 50'W, 860 m alt) from June 2014 to June 2017. The local relief is flat to slightly hilly, and the soil is classified as Dystrophic Red-Yellow Latosol with a medium clay texture (Calderano Filho et al., 1998). The climate of this location is classified as Cwa (Köppen), with two well-defined seasons: a dry season (April to September) with average temperature and precipitation of 19.9 °C and 250 mm, respectively; and a rainy season (October to March) with average temperature and precipitation of 23.0 °C and 1100 mm, respectively.

The first silvopastoral system was implemented in December 2007 and is composed by an *Urochloa* (syn. *Brachiaria*) *decumbens* pasture arborized with Brazilian native trees. These trees were planted in strips spaced 17 m apart, in a near North-South orientation. The strips were composed by three tree lines in a 2.5 × 2.5 m spacing, totaling 545 trees ha⁻¹. The tree species used in the central line of the strips were angico-branco (*Anadenanthera colubrina*), canafístula (*Peltophorum dubium*), ipê-felpudo (*Zeyheria tuberculosa*), jequitibá-branco (*Cariniana estrellensis*), and pau-jacaré (*Piptadenia gonoacantha*). To tutor these species, mutambo (*Guazuma ulmifolia*) and capixingui (*Croton floribundus*) trees were planted at the marginal lines of the strips. Tree thinning of the marginal lines was performed in March 2016 to remove 50% of trees. During the experimental period, tree height ranged from 12 to 20 m, depending on the tree species.

The second silvopastoral system was implemented in April 2011 by

planting *Eucalyptus urograndis* (clone GG100) trees on an already established *Urochloa* (*syn. Brachiaria*) *brizantha* (Hochst ex A. Rich.) Stapf 'BRS Piatã' pasture, in a near East-West orientation. The trees were arranged in single rows spaced 15 m apart, with a 2 m spacing between trees in the lines, which resulted in 333 trees ha⁻¹. Tree thinning was performed in June 2016 to remove 50% of the trees, increasing the spacing to 4 m between trees in the lines. During the experimental period, tree height ranged from 20 to 25 m. Two pasture areas without trees (Full Sun), near the silvopastoral systems, were used to compare traditional livestock production systems with silvopastoral systems.

To characterize the microclimate, photosynthetically active radiation (PAR; $\mu\text{mol m}^{-2} \text{seg}^{-1}$), air temperature (°C), relative humidity (%), wind speed (m seg^{-1}), and black globe temperature (BGT; °C) were measured. For this, the following sensors were used: linear quantum sensors (Apogee, Logan, UT, USA - Accuracy: $\pm 4\%$ of reading), thermo-hygrometers (HC2-S3, Rotronic, Bassersdorf, Swiss - Accuracy: $\pm 0.8\% \text{RH}$, $\pm 0.1^\circ\text{C}$) installed in multi-plate shelters, ultrasonic anemometers (Windsonic, Gill, Lymington, Hampshire, UK - Accuracy: $\pm 2\%$ of reading), and thermocouples copper-constantan (Accuracy: 0.4% of reading) inside a black hollow metallic globe. These sensors were installed 1.5 m above the soil surface, except for the linear quantum sensors which were installed at 0.7 m. The sensors were connected to a data logger (CR3000, Campbell Scientific, Logan, UT, USA) in the system with eucalyptus trees, and to a data logger (CR1000, Campbell Scientific, Logan, UT, USA) in the system with native trees. The data logger were configured to take measurements every 10 s and to record averages every hour. In the silvopastoral systems, the microclimate was measured in transects, with evaluations of air temperature, relative humidity, wind speed, and black globe temperature in two positions, and of PAR in four positions throughout the transects, as shown in Fig. 1. For the installation of the sensors at the position below the trees, a point representative of the cover of the tree canopy was chosen. The same sensors also were installed at the pastures at full sun, which were near the silvopastoral systems. The periods of evaluation were between June 2015 and June 2017 for the system with native trees and between June 2014 and June 2017 for that with eucalyptus trees.

Thermal comfort indexes were calculated using the microclimate data. Black globe and humidity index was calculated using the equation described by Buffington et al. (1981):

$$BGHI = bgt + 0.36 \text{ wbt} + 41.5 \quad (1)$$

where, *bgt* is black globe temperature in °C, and *wbt* is dew point temperature in °C.

Radiant thermal load (RTL) was calculated using the equation described by Esmay (1978):

$$RTL = \sigma \cdot (MRT^4) \quad (2)$$

$$MRT = 100 \cdot \sqrt{\left\{ 2.51 \cdot ws^{0.5} \cdot \langle (bgt+273) - (t+273) \rangle + \left\langle \frac{(bgt+273)}{100} \right\rangle^4 \right\}} \quad (3)$$

where, σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$), MRT is mean radiant temperature in K; *ws* is wind speed in m s^{-1} , and *t* is air temperature in °C.

Meteorological conditions for the experimental period, obtained from a meteorological station near to where the experiments were performed, are presented at Fig. 2. During the rainy season, the average temperature ranged from 22.6 to 23.3 °C, and during the dry season from 19.5 and 20.0 °C. Maximum temperature varied between 29.2 and 30.0 °C in the warmest period. Rainfall varied between 1000 and 1380 mm during the rainy seasons.

PAR incidence on the pastures under full sun and PAR transmission in the silvopastoral systems (hourly average) were assessed for each season. The results obtained for PAR transmission were interpolated

using the natural neighbor method. The measurement positions were compared for the variables: the number of hours per day with BGHI > 79, which is considered as a reference value for the start of thermal stress in bovine (Baeta, 1985; Baeta and Souza, 2010), and RTL during the diurnal period (between 8:00 and 18:00).

The experimental design was completely randomized with repeated measures in time (season of the year) and a 4 × 3 factorial arrangement (season × position). For the statistical analyses, days were considered as a random effect of the model. Analysis of variance was performed through the F test with $P < 0.05$ and means were compared through the Tukey test with $P < 0.05$, using the MIXED procedure of SAS (Littel et al., 2006). To identify the potential of silvopastoral systems to reduce thermal stress in animals, linear regression analyses were performed between hourly means of air temperature at the full sun pastures and BGHI in the silvopastoral and full sun systems. This relationship aimed to identify the temperature for which the value of BGHI is 79.

3. Results

3.1. Silvopastoral systems with Brazilian native trees

The mean hourly variation (from 08:00 to 18:00) in PAR transmission for each season is presented in Fig. 3. PAR transmission was similar between seasons due to the North-South orientation of the tree lines, which results in the apparent movement of the sun transverse to these lines. During the morning, PAR transmission exceeding 80% was obtained facing East, while during the afternoon, higher PAR transmission was obtained facing West. In spring and summer, lower PAR transmission was obtained facing West up to 4.5 m West (between 20% and 30% in the summer) due to the higher growth of tree canopy in this orientation.

The number of hours for which BGHI exceeded 79 and the average RTL are presented in Table 1. There was a significant interaction between season and position for the number of hours with BGHI > 79 ($P < 0.0436$). In all positions, the number of hours with BGHI > 79 was higher in spring and summer than in autumn and winter, such that at the full sun pasture, autumn had more hours with BGHI > 79 than winter. In all seasons, SP-Tree presented lower hours with BGHI > 79 than SP-Pasture and Full Sun; however, in summer and autumn, SP-Pasture also presented less hours with BGHI > 79 than Full Sun. Summer and autumn presented the most significant reductions in the number of hours with BGHI > 79, with 3 h less at SP-Tree than at Full Sun.

For RTL, there was a significant interaction between season and position ($P < 0.001$). Regarding positions in the silvopastoral system, RTL was higher in spring than in the other seasons (Table 1). In the Full Sun pasture, RTL was higher in spring and summer than in autumn and winter. In all seasons, RTL was higher at Full Sun, followed by SP-Pasture and SP-Tree, respectively. In the whole experimental period, there were reductions of at least 17% in SP-Tree compared with Full Sun. In summer, this reduction was up to 22%.

The RFA transmission patterns influenced the hourly fluctuation of BGHI (Fig. 4). Regarding the average of the whole experimental period (Fig. 4A), morning BGHI at the SP-Pasture (point 2 of the Fig. 1A) was higher than at Full Sun, due to the high RFA transmission at this position. At SP-Tree, BGHI was lower than at Full Sun throughout the diurnal period. After 14:00, BGHI was similar at the two silvopastoral positions, with values lower than 79; BGHI at Full Sun was higher than at these positions. In winter and summer, BGHI patterns were the same (Figs. 4B and 4C). In summer, BGHI at Full Sun and SP-Pasture exceeded 85 significant time of the day (Fig. 4C), which is considered to cause stress to animals.

The silvopastoral system reduced the RTL for animals. Considering the average value for the experimental period, RTL achieved up to 700 W m^{-2} at Full Sun, 650 W m^{-2} at SP-Pasture, and 550 W m^{-2} at SP-Tree at times around noon and in the early afternoon. In winter and

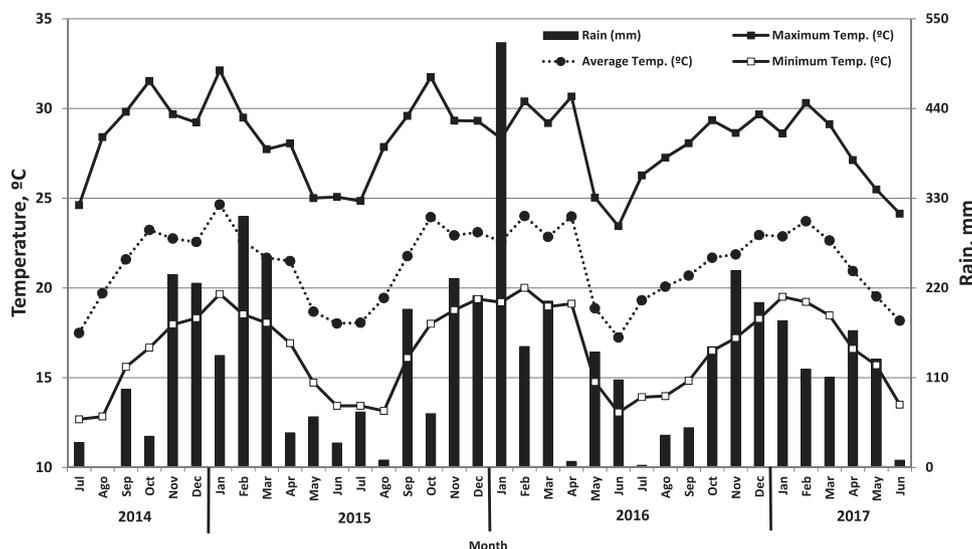


Fig. 2. Monthly temperature (°C) and rainfall (mm) during the experimental period in São Carlos, SP, Brazil.

summer, the RTL patterns remained similar, but in summer, RTL was decreased in the two silvopastoral positions during the diurnal period.

3.2. Silvopastoral system with eucalyptus

PAR transmission by eucalyptus trees differ between seasons (Fig. 5)

due to the East-West orientation of the tree lines, which results in the apparent movement of the sun longitudinal to these lines. In spring and summer, PAR transmission was higher (around 80%) at the positions farthest from the tree lines, because solar declination was near the local latitude. In autumn and winter, PAR transmission was low throughout the silvopastoral system due to the solar declination to North. In winter,

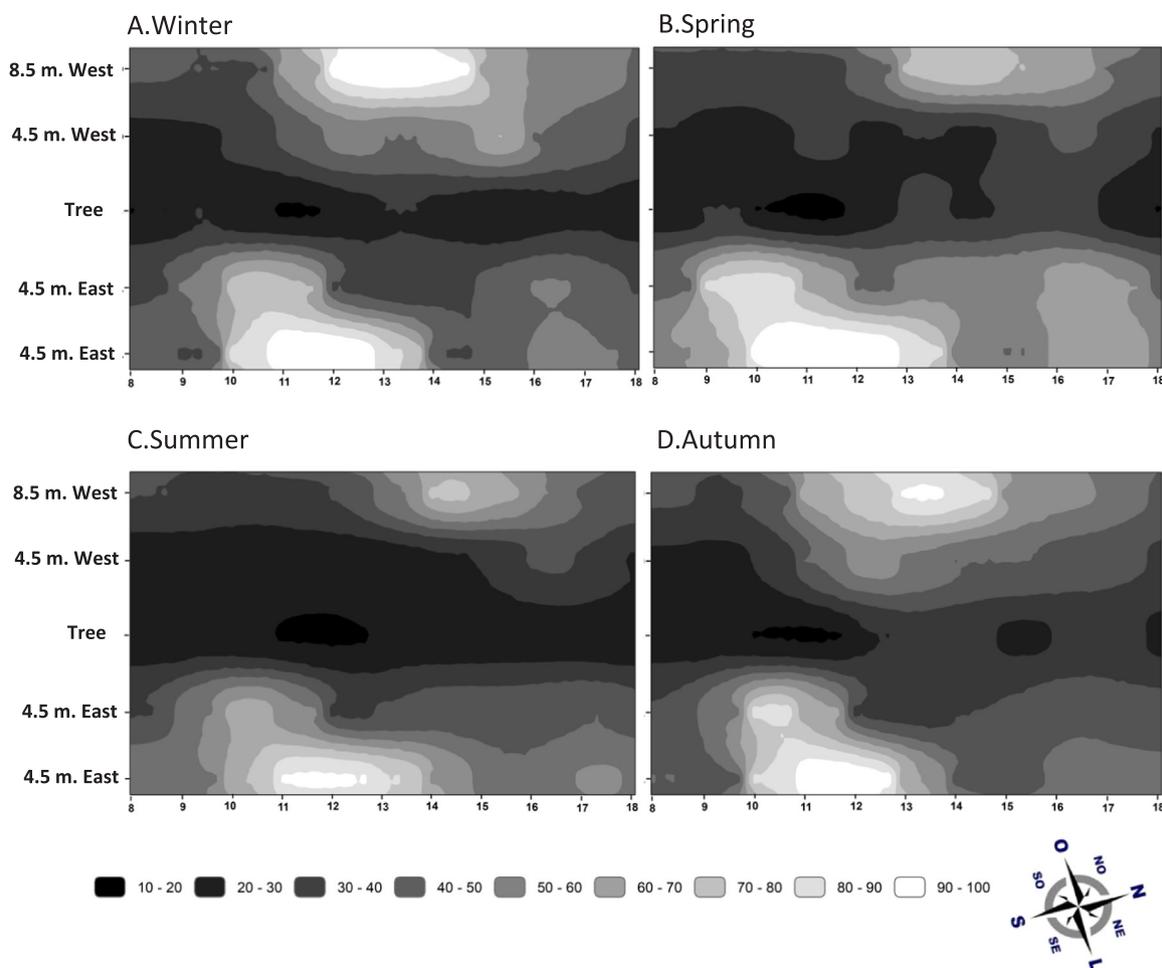


Fig. 3. Spatial and temporal photosynthetically active radiation transmission (%) in the inter-row of a silvopastoral system with Brazilian native trees, every hour during a two-year season between 2015 and 2017.

Table 1

Number of hours with black globe temperature and humidity index (BGHI) higher than 79 and radiant thermal load (RTL) during the day time (8:00–18:00) for each season in a full-sun pasture (Full Sun) and in two positions of a silvopastoral system (SP-Tree and SP-Pasture) with native trees in São Carlos, SP, Brazil.

Position	Season				
	Winter	Spring	Summer	Autumn	Average
	Number of hours with BGHI > 79				
Full Sun	3.2 Ac ⁺	6.4 Aa	6.8 Aa	4.7 Ab	5.2
SP-Tree	1.7 Bb	4.2 Ba	4.0 Ca	1.7 Cb	2.9
SP-Pasture	2.9 Ab	5.8 Aa	5.9 Ba	3.3 Bb	4.6
Average	2.6	5.4	5.6	3.2	
	RTL, W m ⁻²				
Full Sun	599.3 Ab ⁺	633.1 Aa	643.2 Aa	604.8 Ab	620.1
SP-Tree	502.2 Cb	528.9 Ca	504.6 Cb	478.8 Cc	503.7
SP-Pasture	539.3 Bc	591.4 Ba	566.2 Bb	520.8 Bd	554.4
Average	546.9	584.5	571.3	534.8	

* For each variable (Number of hours with BGHI > 79 or RTL) means followed by the same upper-case letter in column are not different. Means followed by the same lower-case letter in a line are not different.

the lowest PAR transmissions occurred by noon at the positions farthest to the tree lines.

There was a significant interaction between season and position when the number of hours with BGHI > 79 was analyzed ($P < 0001$) (Table 2). At Full Sun and in the SP-Pasture, spring and summer had more hours with BGHI > 79 than autumn and winter. In SP-Tree, summer had more hours with BGHI > 79, followed by spring, and autumn and winter, with no difference between them. In spring and summer, the number of hours with BGHI > 79 was not different between Full Sun and SP-Pasture, but was higher at these positions than at SP-Tree. In autumn and winter, the positions in the silvopastoral systems presented less hours with BGHI > 79 than Full Sun.

For RTL, there was significant interaction between season and position ($P < 0.001$) (Table 2). At Full Sun and SP-Pasture, RTL during

the diurnal period was higher in spring and summer than in autumn and winter. At SP-Tree, RTL was higher in spring; followed by summer and winter, with no differences between them; and autumn, respectively. In all seasons, RTL was higher at Full Sun than at the other positions. In winter and autumn, RTL was higher at SP-Tree than at SP-Pasture, while in spring and summer, it was higher at SP-Pasture than at SP-Tree, when tree canopy projected shade mainly on SP-Tree. Regarding the average of the experimental period, RTL decreased by 12% at SP-Tree compared with Full Sun.

Across the experimental period, BGHI was lower in the silvopastoral system than at Full Sun during the day time (Fig. 6A). Differences in the RFA distribution in the silvopastoral system between seasons influenced BGHI fluctuations throughout the day (Figs. 6B and 6C). In winter, BGHI was higher at SP-Tree than at SP-Pasture, while in summer, it was higher at SP-Pasture than at SP-Tree, with SP-Pasture achieving values exceeding those obtained at Full Sun at some times of the day.

RTL was decreased in the silvopastoral system compared with the Full Sun. Regarding the average of the whole experimental period, RTL achieved up to 700 W m⁻² at Full Sun, 620 W m⁻² at SP-Pasture, and 600 W m⁻² at SP-Tree by noon. In winter and summer, RTL in the silvopastoral system presented the same pattern of BGHI, with higher values at SP-Pasture in summer, and higher values at SP-Tree in winter.

In the silvopastoral system containing native trees, values of BGHI exceeded 79 occurred when air temperature (meteorological station) was at least 27.1 °C, while under full sun it occurred at 24.9 °C. In the silvopastoral system containing eucalyptus trees, BGHI was 79 when air temperature was 26 °C, while under full sun this limit was reached with 24.8 °C. These estimates indicate the great potential of such systems to provide improved thermal comfort to animals under climate change scenarios.

4. Discussion

Silvopastoral systems are frequently associated with the thermal comfort of animals. Although several studies have confirmed this association (Paciullo et al., 2011; Baliscei et al., 2013), it is not possible to

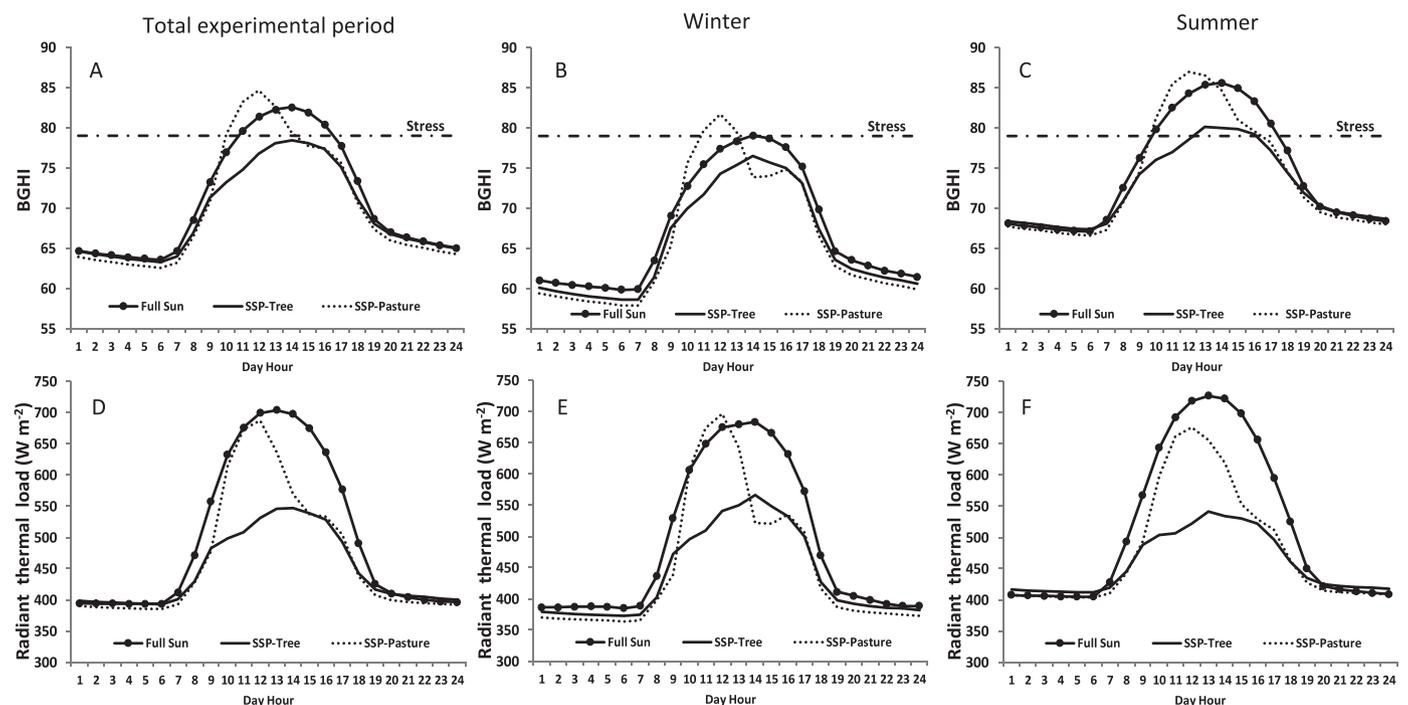


Fig. 4. Average hourly fluctuations in BGHI (A, B, and C) and Radiant thermal load (D, E, and F) throughout the experimental period (A and D), winter (B and E), and summer (C and F) in a pasture at full sun (Full Sun) or in two positions of a silvopastoral system (SP-Tree and SP-Pasture) with Brazilian native trees in São Carlos, SP, Brazil.

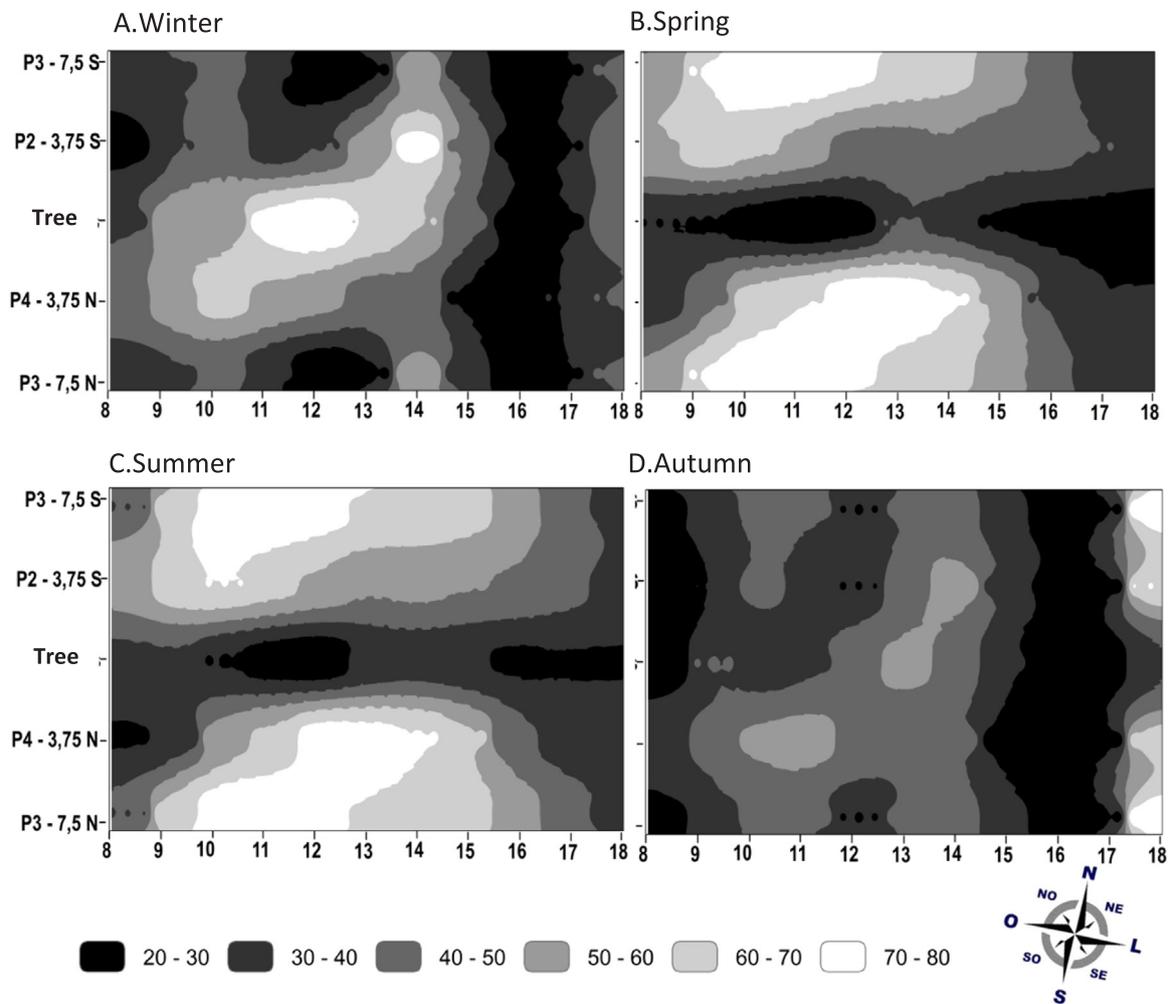


Fig. 5. Spatial and temporal photosynthetically active radiation transmission (%) in the inter-row of a silvopastoral system with eucalyptus trees, every hour during a three-year season between 2014 and 2017.

Table 2

Number of hours with black globe temperature and humidity index (BGHI) higher than 79 and radiant thermal load (RTL) during the day (8:00–18:00) for each season of the year in a full-sun pasture (Full Sun) and in two positions of a silvopastoral system (SP-Tree and SP-Pasture) with eucalyptus in São Carlos, SP, Brazil.

Position	Season of the year				
	Winter	Spring	Summer	Autumn	Average
	Number of hours with BGHI > 79				
Full Sun	3.5 Ac*	6.2 Aa	6.8 Aa	4.5 Ab	5.2
SP-Tree	2.6 Bc	4.9 Bb	5.6 Ba	2.6 Bc	3.9
SP-Pasture	1.2 Cc	6.1 Aa	6.2 Aa	2.2 Bb	3.9
Average	2.4	5.7	6.2	3.1	
	RTL, W m ⁻²				
Full Sun	608.1 Ab*	638.2 Aa	631.3 Aa	596.2 Ab	618.5
SP-Tree	538.0 Bb	560.4 Ca	545.6 Cb	515.1 Bc	539.8
SP-Pasture	498.8 Cb	611.0 Ba	599.0 Ba	501.7 Cb	552.7
Average	548.3	603.2	591.9	537.7	

* For each variable (Number of hours with BGHI > 79 or RTL) means followed by the same upper-case letter in a column are not different. Means followed by the same lower-case letter in line are not different.

state that thermal comfort occurs uniformly across the whole system. In our study, which was conducted in two silvopastoral systems with different tree species and row arrangements, spatial and temporal differences were observed. This was also observed by Schumacher and

Poggiani (1993), Silva and Maia (2013), and Karvatte Jr et al. (2016), who found that changes in the microclimate below trees are associated with morphological characteristics of trees and planting density.

PAR transmission varied as a function of system arrangement throughout the experimental period (Figs. 3 and 5). At some positions of the silvopastoral systems, the attenuation of solar radiation was significant for most of the day; however, in other positions, there was a high incidence of solar radiation. This high incidence, which was associated with reductions in wind speed, promoted an increase in air temperature and humidity (data not presented), as was observed by Oliveira et al. (2017). Moore et al. (2012) showed that high air temperature associated with a high incidence of radiation can result in a thermal environment that is uncomfortable for animals. Black globe temperature considers the effects of air temperature, solar radiation, and wind speed (Kelly and Bond, 1971); its use to calculate thermal comfort indexes promotes the integration of these effects on thermal comfort.

Microclimatic variables influenced thermal comfort indexes in the silvopastoral systems (Figs. 4 and 6). This was evident at the inter-row positions, for which the morning BGHI was higher than that at Full Sun, during the whole experimental period in the system with native trees, and in summer for the system with eucalyptus. Similar results were found for silvopastoral systems in rows (Souza et al., 2007). However, Karvatte Jr. et al. (2016) observed higher thermal comfort at the inter-row in silvopastoral systems with high spacing between rows and lower planting density, due to the higher air movement.

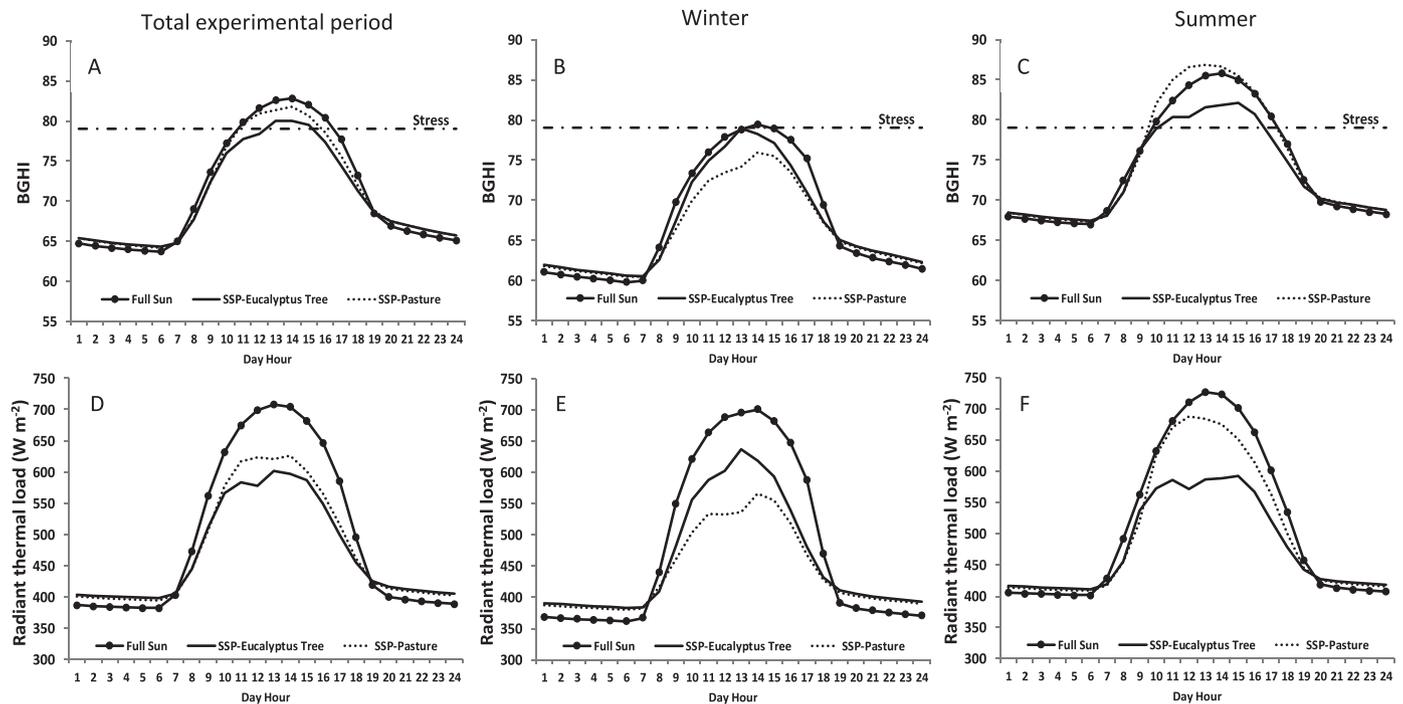


Fig. 6. Average hourly fluctuations in BGHI (A, B, and C) and radiant thermal load (D, E, and F) during the experimental period (A and D), winter (B and E), and summer (C and F) in a pasture at full sun (Full Sun) or in two positions of a silvopastoral system (SP Eucalyptus Tree and SSP-Pasture) with eucalyptus trees in São Carlos, SP, Brazil.

When the two silvopastoral systems in this study were compared, the below-tree canopy (SP-Tree) system with native trees promoted better thermal comfort indexes. This was due to the system arrangement, with triple lines in this system and single lines in the system with eucalyptus. In the SP-Tree, the lowest values for thermal comfort indexes and the lowest number of hours with $BGHI > 79$ were observed. However, in the inter-row, row orientation influenced the results in all seasons by affecting shade projection (Tables 1 and 2, Figs. 4 and 6).

Many studies investigating BGHI in silvopastoral systems have assessed this index at certain times of the year, especially in the summer, or at certain times of the day; and have assessed their results based on averages, absolute values, or as percentage reduction (Navarini et al., 2009; Baliscei et al., 2013; Karvatte Jr. et al. 2016). In our study, comparisons were made using hourly averages for long periods (Figs. 4 and 6). At times close to noon, the BGHI reduced by approximately 4–5, which is similar to the results reported by Navarini et al. (2009) and Carvalho et al. (2017).

Despite its position, SP-Tree presented higher animal thermal comfort, with a significant number of hours $BGHI > 79$ at this position, with 4.2 h per day in spring in the system with native trees (Tables 1), and 5.6 h per day in the summer in the system with eucalyptus (Table 2). This has previously been reported for Brazilian tropical regions in studies with silvopastoral systems in the Cerrado biome (Karvatte Jr. et al., 2016) and in the Atlantic Forest under artificial shading (Ablas et al., 2007). Although arborized systems promote higher thermal comfort, Baeta (1985) studies showed that values for thermal comfort indexes were within the warning zone ($BGHI > 79$). Thermal comfort is also associated with a higher grazing time, which was observed in the present study in summer (data not presented).

Trees reduced the incidence of solar radiation and consequently, of radiant thermal load, which varied as a function of system arrangement and position. The greatest reductions in RTL occurred in the system with native trees, achieving up to 27% at warmest times of the day (Fig. 4F). In the system with eucalyptus, RTL was reduced by 20%. These values are slightly higher than those reported by Carvalho et al. (2017) for a silvopastoral system with eucalyptus in the Brazilian

savannah, and similar to those obtained reported by Baliscei et al. (2013), who observed a 18% reduction in RTL in summer by noon. In the Brazilian Northeast, which has a semi-arid climate, Souza et al. (2010) found a 31% reduction in RTL under shading.

Long-term microclimatic measurements and determination of thermal comfort indexes in silvopastoral systems enable the potential of silvopastoral systems for the improvement of animal thermal comfort to be characterized. Although some uncomfortable conditions were observed in the assessed positions, the potential of these systems to improve thermal comfort was confirmed. Under the same temperature, the silvopastoral systems presented lower BGHI compared with the full-sun pastures (Fig. 7).

When the potential of thermal comfort is analyzed in silvopastoral systems, it is necessary to consider that a balance is important to maintain the production of all components in integrated livestock production systems. In this context, excessively high levels of solar radiation interception, as occurred in some periods of our study (Figs. 3 and 5), may reduce forage production, especially for tropical pastures. To solve this problem, another thinning could be performed.

In general, silvopastoral systems are considered beneficial for animal welfare, despite their great variability of arrangements, especially in relation to tree or pasture species, and tree spacing (Silva-Pando et al., 2002; Navarini et al., 2009; Joele et al., 2017; Karvatte Junior et al., 2016). Sheep reared in silvopastoral systems increase their time in grazing and reduce in 10% their water consume (Souza et al., 2015). Beef or dairy cows, even when raised under temperate climates, make use of natural shading when BGT and the other thermal comfort indexes are increased, which reduces their respiratory frequency and panting score (Van Laer et al., 2015). In tropical climates, silvopastoral systems do not change time in grazing, rumination and idleness of beef cows at the warmest times of the day, but reduce in almost 1.0 °C dorsal surface temperature, compared to cows raised under full sun (Giro, 2018).

Therefore, the reductions in air temperature and BGHI in silvopastoral systems seems to be beneficial to several animal species. However, decreases in RTL, caused by trees, seems to have more important effects on water buffaloes, which are animals with intense epidermal

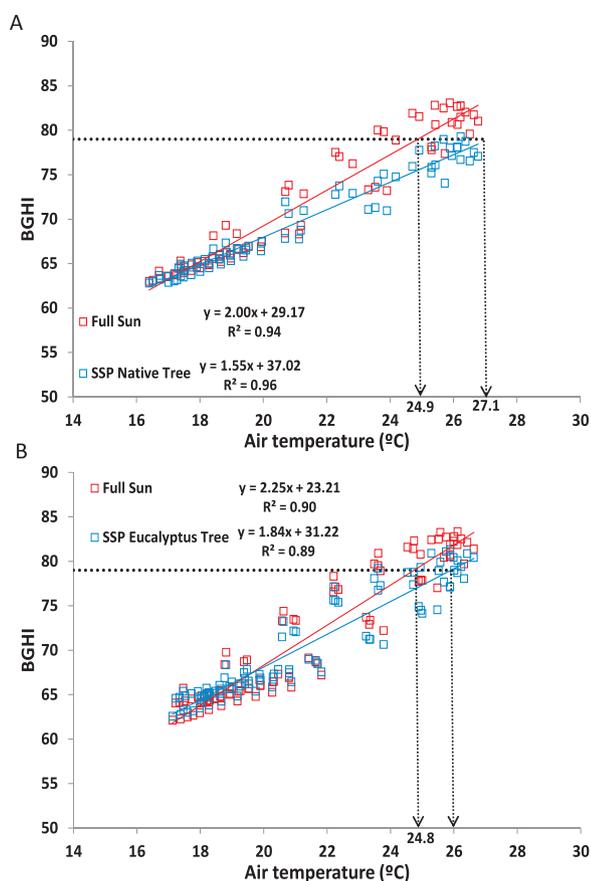


Fig. 7. Relationship between hourly average air temperature (from 0 to 24 h) in a full-sun pasture and BGHI in the pastures under full sun or in silvopastoral systems with Brazilian native trees (A) or eucalyptus trees (B), in São Carlos, SP, Brazil.

pigmentation and with low reflectivity, characteristics that cause high absorption of solar radiation (Garcia, 2013). In fact, buffaloes raised in silvopastoral systems present lower cardiac frequency than animals kept under full sun, due to the need of dissipation of corporal heat (Garcia et al., 2011), besides that present lower concentration of serum cortisol (Silva et al., 2014), an important indicator of stress.

5. Conclusions

Microclimatic changes induced by trees, mainly relating to the transmission of solar radiation, promoted higher animal thermal comfort in the silvopastoral systems, with a lower number of hours of thermal stress and a lower radiant thermal load. The arrangement of systems, such as planting density and row orientation, influenced thermal comfort. Additionally, silvopastoral systems may help livestock to adapt to climate change, providing lower BGHI values at the same temperature compared with a full sun pasture.

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