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Microclimate without shade and silvopastoral system during summer and winter

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ABSTRACT. This study evaluated the microclimate in a system without shade (WS) and in a silvopastoral system (SP) with eucalyptus during summer and winter, by measuring the air temperature (Ta), black globe temperature (Tg), relative humidity (RH), wind speed (Ws), every 2 hours for 24 hours between rows, shade (SP) and no shade effect (WS). It was employed the randomized blocks design (months), in the plots (systems), subplots (hours) and sub-subplots (seasons). Except for Ta and RH, the Tg (24.73, 26.41°C), Ws (3.16, 4.57 $m\ s^{-1}$), Black globe-humidity index (BGHI) (71.83, 73.84), Thermal load index (TLI) (74.53, 76.11) and Radiant thermal load (RTL) (526.46, 595.80 $W\ m^{-2}$), respectively for SP and WS, were higher in WS. Ta, RH and Ws had a quadratic effect of hour. There was an effect of season, respectively in summer and winter, on the Ta (27.55, 14.93°C), RH (72.11, 60.68%), Tg (29.80, 21.33°C), BGHI (80.04, 65.63), TLI (81.64, 69.00) and RTL (575.65, 546.61 $W\ m^{-2}$). Tg, RH and RTL showed an interaction of season x hour, and a quadratic effect, and the RTL had an interaction of system x season. The Tg was correlated with BGHI (0.962), TLI (0.956) and RTL (0.809). The silvopastoral system decreased the Tg and Ws, and made the environment more harmonious by decreasing the climatic differences between seasons.

Keywords: thermal comfort, seasons, index, silvopastoral, shade.

Microclima no sistema sem sombra e silvipastoril no verão e no inverno

RESUMO. Avaliou-se o microclima em sistema sem sombra (SS) e silvipastoril (SP) com eucalipto no verão e inverno, medindo-se as variáveis temperatura do ar (Ta), globo negro (Tg), umidade relativa (UR), velocidade do vento (Vv) a cada 2 por 24h (entre renques, sombra (SP) e sem efeito de sombra (SS)). O delineamento foi em blocos casualizados (mês), na parcela (sistema), na subparcela (horas) e na sub-subparcela (estação). Com exceção da Ta e UR, a Tg (24,73 e 26,41ºC), Vv (3,16 e 4,57 $m\ s^{-1}$), ITGU (71,83 e 73,84), ICC (74,53 e 76,11) e CTR (526,46 e 595,80 $W\ m^{-2}$), respectivamente, para SP e SS, foram maiores no SS. A Ta, UR e Vv sofreram efeito quadrático do horário. Verificou-se efeito da estação, respectivamente, no verão e inverno a Ta (27,55; 14,93ºC), UR (72,11; 60,68%), Tg (29,80; 21,33ºC), ITGU (80,04; 65,63), ICC (81,64; 69,00) e CTR (575,65; 546,61 $W\ m^{-2}$). A Tg, UR e CTR sofreram interação da hora x estação, e efeito quadrático, a CTR interação com sistema x estação. A Tg correlacionou-se com ITGU (0,962), ICC (0,956) e CTR (0,809). O sistema silvipastoril reduziu Tg e Vv e tornou o ambiente mais harmônico diminuindo as diferenças climáticas entre as estações.

Palavras-chave: conforto térmico, estações, índices, sistemas, silvipastoril, sombra.

Introduction

Developing countries have adopted production models increasingly intensive for animal production. The international literature is extensive in the checks on the environmental factors that impose some stress to ruminants, and the performance is the result of the homoeothermic functioning, among other factors, and a dysfunction in this system leads to significant changes in the efficiency of production (NUNES et al., 2003), and for Souza et al. (2010a), the climate is the major factor affecting animal production.

Barbosa et al. (2004) affirm that the provision of shade is efficient to provide comfort to the animals, because it reduces the direct radiation. According to Kazama et al. (2008), this provision of shade besides protecting against thermal radiation, also helps in maintenance of animal productivity by reducing the heat load associated with solar radiation.

Soares et al. (2009) observed that the presence of trees causes the formation of microclimate areas, with lower wind speed and solar radiation, which according to Mader and Davis (2003), provides protection, being a useful tool to help animals to face environmental stress.

The animals differ in their ability to cope with climatic variations, and the objective of the indices to combine environmental variables comparing with physiological responses, behavioral and productive, allowing their evaluation (SILVA, 2008).

In this way, the present experiment aimed to evaluate the climatic conditions in two systems, without shade and silvopastoral system formed by double rows of eucalyptus, during the summer and winter.

Material and methods

The experiment was conducted in the northwestern region of Paraná State, in the municipality of Paranavaí at coordinates 22°44' South and 52°28' West, and altitude of 453 m. The climate according to Köppen is Cfa mesothermal humid subtropical, characterized by hot summer and infrequent frosts, with the rainfall concentrated during the summer months, without a well-defined dry season (CAVIGLIONE et al., 2000).

It was evaluated the microclimate in the system without shade (WS) and silvopastoral system (SP), formed with star grass (*Cynodon plectostachyrus*), intercropped with eucalyptus tree, with two year of deployment, average height of 8 m. The trees were arranged in double rows, at the ground level, with a density of 290 trees per hectare, 2.5 m space between trees, and 25 m space between rows.

The data was collected during the months of December 2009 to March 2010 in 15 summer days, and in the months from June to September 2010, 16 winter days. The days for data collection were sunny and with no rainfall. The data were obtained every 2 hours for 24 hours simultaneously in the systems, adding up to of 2,976 readings.

For the silvopastoral system (SP), we recorded the rainfall in the period, air temperature (Ta), the relative humidity (RH), wind speed (Ws) and the black globe temperature (Tg), always in the same sequence of rows, in the geometric center of the shade (mobile location), and between the rows (fixed location). For the system without shade (WS), these variables were measured at a fixed location.

The variables Ta and RH were collected in an instant reading using a thermo-hygroanemometer (Kestrel 3000®), the variable Ws was obtained by averaging the maximum and minimum values in ten seconds of reading, once it is greatly variable. The Tg was obtained with the use of a globe with black plastic sphere (15 cm diameter) and alcohol column thermometer. The dew point temperature (Tdp) and partial pressure of water vapor (Pp) were obtained by psychometrics equations.

To evaluate the environments, the equipment was placed 1.60 m above the ground, simulating the height of the dorsum of the animals. With respect to the horizontal position, the equipment were placed at a distance of 0.5 m from the trunk of the trees in the center of the shadow, and moved according to the movement of the shadow, and at night, in a fixed point.

For the interpretation of data, we used the following indices of thermal comfort:

a) Black globe-humidity index (BGHI), proposed by Buffington et al. (1981):

$$BGHI = Tg + 0.36Tdp + 41.5$$

where:

Tg = black globe temperature (°C); Tdp = dew point temperature (°C).

where:

$Tdp = 273.15[0.971452 – 0.057904 \log_e Pp\{Ta\}]^{-1} - 273.15$; Pp{Ta} = partial pressure of water vapor in relation to Ta.

where:

$Pp\{Ta\} = PS\{Ta\} \times RH)/100$; $PS\{Ta\} = 0.61078 \times 10^{(7.5 \times Ta)/(Ta+237.5)}$; RH = relative humidity, decimal; Ta = air temperature (°C).

b) Thermal load index (TLI), developed by Gaughan et al. (2002):

$$TLI = 33.2 + 0.2\,RH + 1.2\,Tg - (0.82\,Ws)0.1 – \log(0.4\,Ws^2 + 0.0001)$$

where:

Tg = black globe temperature (°C); RH = relative humidity, decimal; Ws = wind speed, in m s^{-1}.

c) Radiant thermal load (RTL), proposed by Esmay (1979):

$$RTL = óT_{mr}^{4}, W\ m^{-2}$$

where:

ó = constant of Stefan-Boltzmann (5.67×10^{-8}, $W.m^{-2}\ K^{-4}$); T_{mr} = mean radiant temperature (°K); $T_{mr} = 100\ \{2.51\ Ws^{0.5}\ ((Tg - Ta) + ((Tg + 273.15) / 100)^4\}^{0.25}$.

where:

Ta = air temperature (°C); Tg = black globe temperature (°C); Ws = wind speed, in m s^{-1}.

The treatments were arranged in a split plot randomized block design (months), in a plot with two systems (SP and WS), in a sub-subplot with 12 hours (2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22 and 24) and a sub-subplotwith two seasons (summer and winter) performing repetitions (15 days in the summer and 16 days in the winter).

The average of hours observation was subjected to analysis of variance and means were compared by Tukey's test at 5% and the regressions were selected by F test ($p < 0.05$) using the program SISVAR (FERREIRA, 2008), with the following mathematical model:

$$Y_{ijk} = \mu + A_i + B_j + e_{ij} + H_k + AH_{lk} + e_{ijk} + C_l + \\ + AC_{Il} + HC_{kl} + e_{ijkl}$$

where:

$Yijk$ = response variable; μ = overall mean; A_i = effect of the system, i = 1 and 2; B_j = effect of the block j, j = 1 and 2; e_{ij} = error (a); H_k = effect of the hour (subplot) k, k = 1 to 12; AH_{lk} = interaction effect of system x hours; E_{ijk} = error (b); C_l = effect of the sub-subplot (season) l, l = 1 and 2; AC_{il} = interaction effect of system x season; HC_{kl} = interaction effect hours x season; e_{ijkl} = experimental error(c).

The data were analyzed using the SAS statistical program (SAS, 2008), and procedures GLM, REG and CORR.

Results and discussion

During the study period, the rainfall was normal for the region (Figure 1). According to Caviglione et al. (2000), there is a trend of rainfall to be concentrated in summer months, with low precipitation in winter.

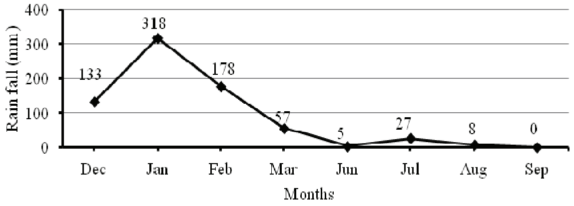

Figure1. Index of rainfall (mm) during the months of data collection.

No difference was found ($p > 0.05$) for climatic variables Ta and RH between the SP and WS systems (Table 1). Barbosa et al. (2004) explained that the use of shade changes the radiation balance of the animal, but has no effect on the temperature and air humidity, confirming Buffington et al. (1983) that stated the primary purpose of shade is to protect the animals from intense, direct solar radiation and diffused and reflected radiation.

The Tg (24.73°C) and Ws (3.16 m s^{-1}) were lower ($p < 0.05$) in the SP system in relation to the WS system, with values of 26.41°C to Tg and 4.57 m s^{-1} for Ws. Both in summer and winter, Leme et al. (2005) observed lower Tg values in the shade compared with those under the sun showing that the presence of trees improves the environment as a whole.

Table 1. Mean values and standard errors of air temperature (Ta) (°C), relative humidity (RH) (%), black globe temperature (Tg) (°C), wind speed (Ws) (m s^{-1}), black globe-humidity index (BGHI), thermal load index (TLI) and radiant thermal load (RTL) (W m^{-2}) in the different systems.

Variables	Systems	
	SP	WS
Ta (°C)	21.26 ± 0.79 a	21.22 ± 0.79 a
RH (%)	66.43 ± 1.62 a	66.35 ± 1.63 a
Tg (°C)	24.73 ± 0.84 b	26.41 ± 0.99 a
Ws (m s^{-1})	3.16 ± 0.17 b	4.57 ± 0.21 a
BGHI	71.83 ± 1.05 b	73.84 ± 1.20 a
TLI	74.53 ± 0.91 b	76.11 ± 1.06 a
RTL (W m^{-2})	526.46 ± 15.85 b	595.80 ± 2.3.86 a

Means followed by the same letter in the rows are not different by Tukey's test at 5%, SP = silvopastoral system; WS = system without shade.

Soares et al. (2009), with *Pinus taeda* trees in open-air area and spacing 15 x 3 and 9 x 3 m, found for Ws, respectively, values of 1.81, 1.11 and 0.76 m s^{-1}, and concluded that the presence of trees causes the formation of microclimate with lower wind speed.

The BGHI (71.83 and 73.84), TLI (74.53 and 76.11) and RTL (526.46 and 595.80 W m^{-2}), respectively, for SP and WS, were affected by the type of system ($p < 0.05$), lower for the SP system, where the presence of trees reduced the load of radiation and wind speed, improving thus environmental conditions. The values are consistent with those obtained by Souza et al. (2010b) who found in summer BGHI maximum values of 89.3 and 90.4, TLI 79.7 and 83.4 and RTL 637.2 and 709.9 W m^{-2}, respectively, for SP and WS, assuring that the presence of trees improves the environment and the thermal comfort of the animals compared with the non-shaded environment.

The Ta featured a quadratic effect ($p < 0.05$) for the time of day (Figure 2a), with a maximum of 24.13°C in SP and 24.41°C in WS, both at 14h. Superior result was observed by Azevedo et al. (2005) that found Ta of 27.1°C in the afternoon. According to Silva (2008), the atmosphere absorbs the energy of the solar direct radiation and gets heat, and transfers this accumulated energy by increasing the air temperature.

For RH (Figure 2b), there was a quadratic effect of hour of day ($p < 0.05$), where in the minimum value was 54.8% in SP and 54.6% in WS both at 14h. Faria et al. (2011) and Barbosa et al. (2004) observed similar results for RH, with obtained values of 56 and 46%,respectively, by the afternoon. The lower values of RH in the hottest hours of the day favor the loss of heat by evaporative processes.

The predicted value for the wind speed (Ws) (Figure 2c) had a quadratic effect for hour of day ($p < 0.05$), with a maximum value of 3.8 m s^{-1}, at 11h in SP and 5.0 m s^{-1}, at 12h in WS, differently from Faria et al. (2011) that observed in the afternoon Ws of the highest average, 0.55 m s^{-1}. For Volpe and Schöffel (2001), the surface wind is caused mainly by the difference in temperature and pressure between two places, causing the horizontal movement of air, where the relief has an effect very pronounced on the predominant direction.

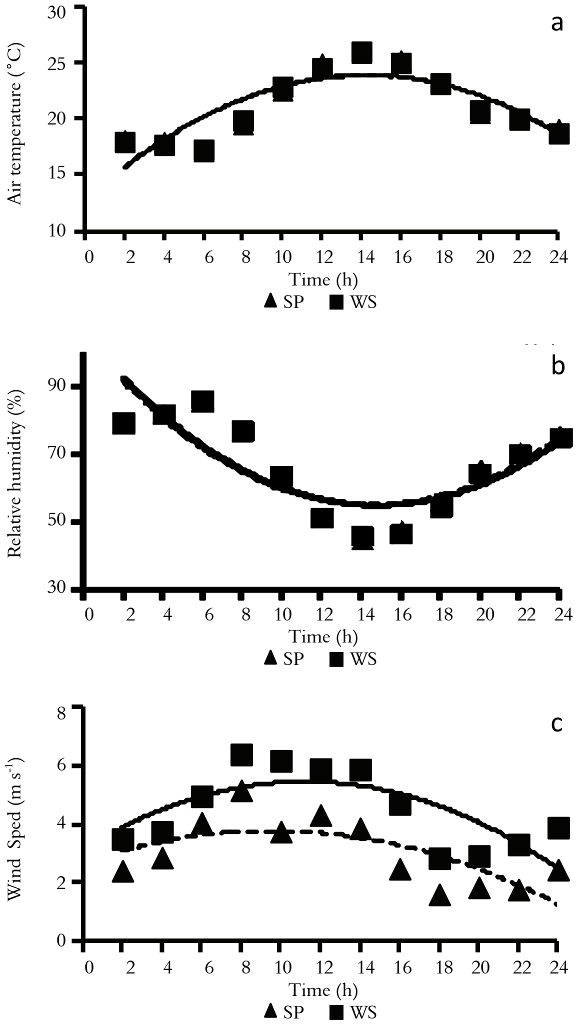

Figure 2. Values of air temperature (Ta): (♦) SP = $12.79 + 1.65H – 0.06H^2$($r^2 = 0.69$), (■) WS = $11.39 + 1.91H - 0.07H^2$ ($r^2 = 0.73$) (a); relative humidity (RH): (♦) SP = $102.50 – 6.62H - 0.23H^2$ ($r^2 = 0.66$), (■) WS = $100.72 – 6.51H + 0.23H^2$($r^2 = 0.65$) (b) wind speed (♦) (Ws): SP = $2.59 + 0.22H –0.01H^2$ ($r^2 = 0.47$); (■) WS = $2.37 + 0.46H –0.02H^2$ ($r^2 = 0.62$) (c), according to time of observation.

The Tg (Figure 3a) was affected by the interaction between system and time, with a quadratic effect ($p < 0.05$) with a maximum of 30.63°C occurring at 14h in SP and 32.40°C in WS at 13h. The presence of the shade explains the lower temperature in the SP system, as well as the delay in the schedule of maximum.

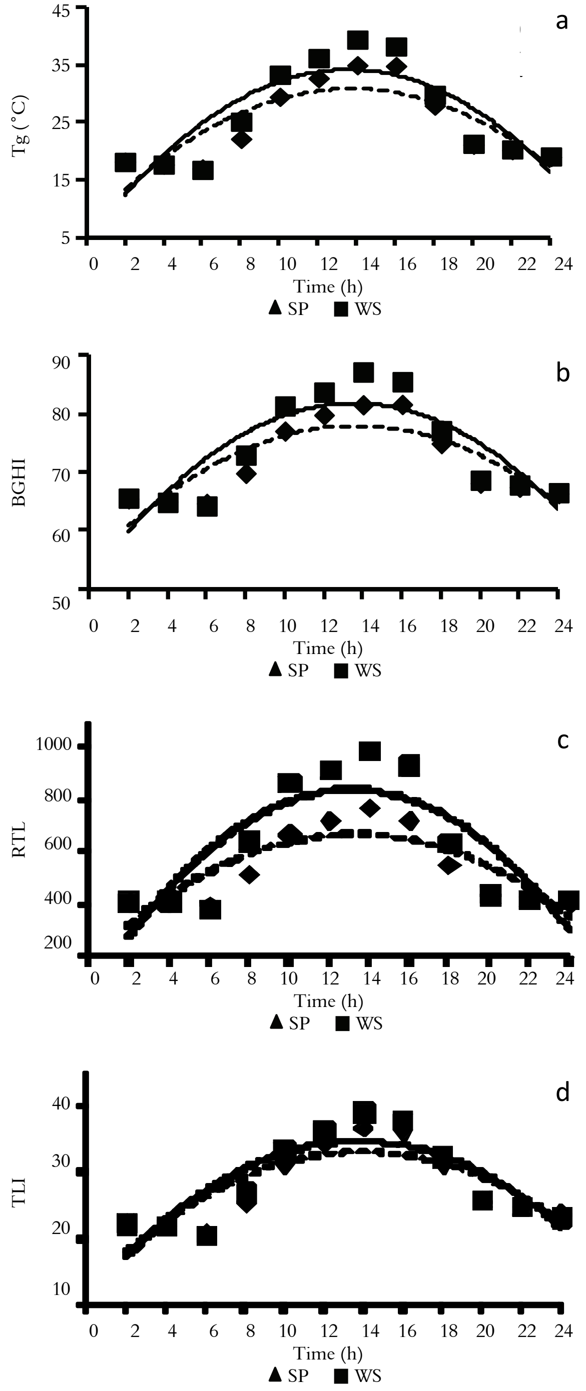

Figure 3. Values of the black globe temperature Tg: (♦) SP = $12.99 + 2.52H - 0.09H^2$($r^2 = 0.56$), (■) WS = $11.71 + 3.28H - 0.13H^2$ ($r^2 = 0.59$) (a); black globe-humidity index (BGHI): (♦) SP = $60.43 + 2.50H - 0.09H^2$ ($r^2 = 0.58$), (■) WS = $59.15 + 3.29H - 0.13H^2$($r^2 = 0.58$) (b) radiant thermal load (RTL): SP = $296.28 + 56.22H - 2.30H^2$ ($r^2 = 0.58$); WS = $229.40 + 90.75H - 3.75H^2$ ($r^2 = 0.61$) (c), thermal load index (TLI): SP = $65.05 + 2.14H - 0.08H^2$ ($r^2 = 0,58$), WS = $63.05 + 3.09H - 0.12H^2$ ($r^2 = 0.62$) (d), according to time of observation.

Between seasons (Table 2), Ta was higher ($p < 0.05$) in summer, with 27.55°C, than winter, with 14.84°C. This result is similar to that found by Campos et al. (2005) analyzing the thermal conditions of housing for calves in the same region, which observed a difference in Ta between summer and winter, respectively, with 31 and 23.1°C. The difference in Ta is explained by Escobar (2007) showing that during winter, the region is affected by the passage of intense cold air masses that sometimes tend to persist for sever al days.

Table 2. Mean values and standard errors of air temperature (Ta) (°C) temperature black globe (Tg) (°C), wind speed (Ws) ($m\ s^{-1}$) black globe-humidity index (BGHI) thermal load index (TLI) and radiant thermal load (RTL) ($W\ m^{-2}$), as a function of the seasons.

Variables	Season	
	Summer	Winter
Ta (°C)	27.55 ± 0.41 a	14.93 ± 0.49 b
RH (%)	72.11 ± 1.34 a	60.68 ± 1.70 b
Tg (°C)	29.80 ± 0.84 a	21.33 ± 0.79 b
Ws ($m\ s^{-1}$)	3.82 ± 0.24 a	3.91 ± 0.17 a
BGHI	80.04 ± 0.90 a	65.63 ± 0.82 b
TLI	81.64 ± 0.79 a	69.00 ± 0.70 b
RTL ($W\ m^{-2}$)	575.65 ± 16.77 a	546.61 ± 23.36 b

Means followed by the same letter in the rows are not different by Tukey's test at 5%.

Ortêncio Filho et al. (2001) observed higher Tg value, in the summer, in the afternoon, with 34.85°C under the sun, while in the shade with 27.62°C, and this result was related to the incidence of solar radiation, that reaches its peak at midday and remain elevated up to 16h.

The BGHI (Figure 3b) was also affected by the interaction between system and time ($p < 0.05$), with a quadratic effect, with a maximum of 77.79 at 14h in SP, and 79.96 at 13h in WS, consistent with Kazama et al. (2008) that noted highest values of BGHI between 10 hours and 16 hours in the sun and the shade, indicating that the incidence of heat load reaches its peak at these times. Barbosa et al. (2004) found superior results, with maximum values of BGHI, in the afternoon, under the sun of 95 and in the shade of 88.

The RTL (Figure 3c) was influenced by the interaction between system and time, with a quadratic effect ($p < 0.05$), whereas the maximum was 639.83 $W\ m^{-2}$ in SP and 778.44 $W\ m^{-2}$ in the WS, both at 12h, corroborating with Souza et al. (2010b) that found the maximum value of 763.5 $W\ m^{-2}$ at 13h in the sun and 530.2 $W\ m^{-2}$ at 14h in the shade, showing the importance of shade in reducing radiant heat load on animals.

The TLI (Figure 3d) was also influenced by the interaction between system and time, with a quadratic effect ($p < 0.05$), and the maximum was 78.84 in the SP and 82.94 in WS, both at 13h, consistently to Souza et al. (2010b), that found a point of maximum of 79.7 at 14:33h and 83.4 to 14:22h, respectively, for SP and WS 8m height. Silva et al. (2007) showed that the TLI is the most indicated to evaluate heat stress for dairy cattle adapted to tropical environments with a significant correlation of 0.286 with the rectal temperature and 0.542 with respiratory rate.

The Tg followed Ta, being higher ($p < 0.05$) in summer (29.80°C) than winter (21.33°C). Ortêncio Filho et al. (2001), studying sheep, verified the maximum Tg of 40.5°C under the summer sun, compared to the winter with 34.8°C, relating the results to the incidence of solar radiation, supported by Silva (2006) who stated that the position or rise of the sun affects the amount of radiation received, and in the regions along the parallel 23° the radiation is more intense in summer than in winter.

Higher RH was found ($p < 0.05$) in summer (72.11%) compared to winter (60.68%) and can be explained by rainfall (Figure 1), which achieved 674 mm in summer and 55 mm in winter, contributing to the effect of air moisture between seasons. This agrees with Lima et al. (2003) who observed an average of RH of 78.6% in the dry season and 80.94% in the wet season, ascribing this result to the precipitation in the period. Likewise, the results were similar to those of Azevedo et al. (2005) that also found RH of 71% in the summer and 63.5% in the winter.

The BGHI was higher ($p < 0.05$) in summer (80.04) than in winter (65.63). As the BGHI is based on the measurements of Tg and dew point temperature (Tdp), which in turn is determined by RH and Ta, showed higher values in summer in part due to the greater values of Ta and Tdp, and also by the Sun-Earth relationship.

The TLI was higher ($p < 0.05$) in summer (81.64) than in winter (69.00). As these are average values, and not consider the extremes, which in summer had values above 95, indicating danger, and in winter they not reached 89, the TLI was considered safe for dairy cows in tropical environment (Silva et al., 2007). These variations can be explained by the values of RH and Tg (Table 2), which, when lower in winter, change the TLI in this season.

The RTL was higher ($p < 0.05$) in summer (575.65 $W\ m^{-2}$) than in winter (546.61 $W\ m^{-2}$), indicating more radiation in the summer, but during winter the values were also high, showing that the radiation received by the animals on the field remains high throughout the season. Amaral et al. (2009), in the same region, obtained value of RTL by the morning in summer of 1.225.33 $W\ m^{-2}$, and in winter by the afternoon of 872.25 $W\ m^{-2}$.

The RTL was lower ($p < 0.05$) (Table 3) in the SP (530.04 and 522.85 W m^{-2}) than in WS (621.29 and 570.31 W m^{-2}), respectively, in summer and winter.

Table 3. Mean values and standard errors of the radiant thermal load (RTL) (W m^{-2}) depending on the season and the system used.

Season	System		
	SP	WS	CV %
Summer	530.02 ± 15.72 bA	621.29 ± 30.89 aA	10.59
Winter	522.92 ± 29.65 bA	570.31 ± 39.27 aB	

Means followed by the same uppercase in the columns and lowercase in the rowsare not different by Tukey's test at 5%, SP = silvopastoral system; WS= system without shade, CV = coefficient of variation.

The difference between the systems was caused by the shade that provides protection against direct radiation compared to an open air environment. The use of shade structures can reduce the solar load by up 30% (BOND; LASTER, 1975), indicating that becomes more important the shade in warmer environmental conditions (NONAKA et al., 2008; SCHUTZ et al., 2010, TUCKER et al., 2008). However, even in the shade, the heat load can be significant, and in the SP, although higher in summer than winter, there was no significant difference ($p > 0.05$) evidencing that the presence of trees maintained the environment more stable between seasons with an amplitude of variation of 7.1 W m^{-2}. Nevertheless, in the WS with amplitude of 50.98 W m^{-2} there was a significant difference ($p < 0.05$) between the seasons, showing that without protection, the environment is exposed to greater variability. The lowest radiation received during the winter would be by the inclination axis of the earth in this season (SEN, 2008).

The Tg (Figure 4a) was affected by the interaction of the time and season, with a quadratic effect ($p < 0.05$) and the maximum of 36.14°C in summer at 13h, and 27.94°C in winter at 15h. The lowest value of Tg in the winter can be explained by the lower Ta in winter (Table 2), which cooled the globe and kept lower its temperature, as well as the difference of time at the maximum, spending more time to warm up in winter.

The RH (Figure 4b) was affected by the interaction of the time and season, with a quadratic effect ($p < 0.05$), and a minimum value of 63.06% at 15h in summer, and 51.66% at 18h in winter, opposite result of Ta (Figure 1b), confirming Silva (2008) who affirmed that the RH can only be understood in terms of Ta.

The RTL (Figure 4c) was influenced by the interaction of the time and season, with a quadratic effect ($p < 0.05$), and the maximum of 704.01 W m^{-2} and 714.36 W m^{-2} at 12h, respectively, in summer and winter. Results obtained by Campos et al. (2005) showed maximum levels of RTL 667.74 W m^{-2} by the afternoon in the spring/summer and lowest with 606.51 W m^{-2} in the autumn/winter for non-shaded areas, and assigned the lowest value to the milder temperature sand, probably, to the high incidence of winds, more intense during autumn/winter.

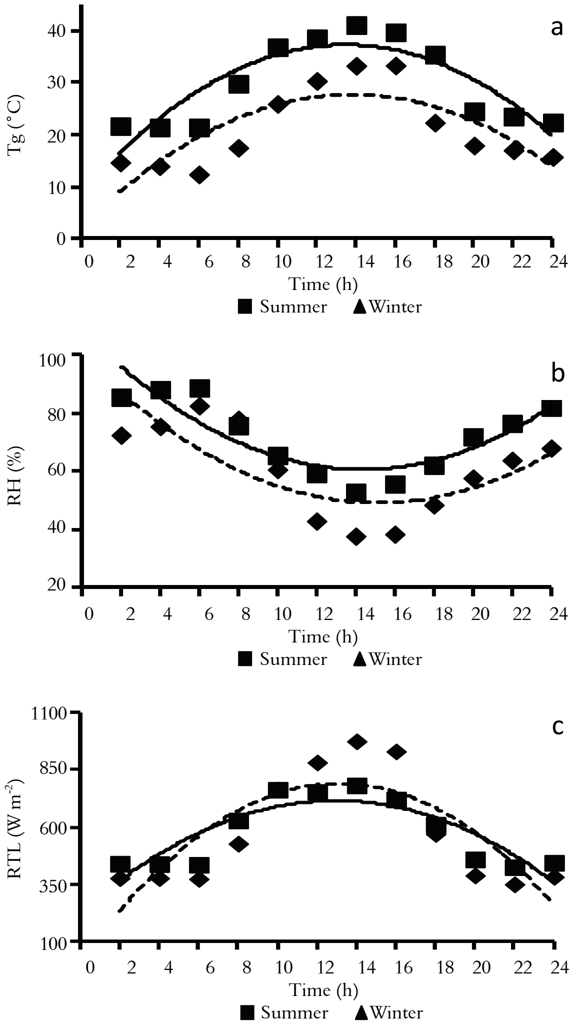

Figure 4. Values of black globe temperature (Tg): (■) Summer = $15.54 + 3.21H - 0.12H^2$ ($r^2 = 0.63$), (♦) Winter = $9.16 + 2.60H - 0.09H^2$ ($r^2 = 0.49$) (a), relative humidity (RH): (■) Summer = $94.12 - 4.17H + 0.14H^2$ ($r^2 = 0.59$), (♦) Winter = $81.85 - 3.44H + 0.09H^2$ ($r^2 = 0.42$) (b), radiant thermal load (RTL): (■) Summer = $323.13 + 63.54H - 2.64H^2$ ($r^2 = 0.67$); (♦) Winter = $202.56 + 83.43H - 3.40 H^2$ ($r^2 = 0.53$) (c), according to time of observation.

According to Sampaio et al. (2004) the thermal environment of an area shaded or not is evaluated in terms of thermal comfort indices. Usually, these indices consider the environmental parameters of temperature, humidity, wind and radiation, and each parameter has a certain weight within the index, according to their relative importance to the animal.

The Tg was the environmental variable with the highest correlation (Table 4) with RTL, TLI and BGHI, indicating its importance on the composition of these indices, all high and positive pointing that when this variable increases, also increase the value of these indices, higher for BGHI (0.962), followed by TLI (0.956) and RTL (0.809). These results confirm that the in crease of the radiant energy is important in determining thermal comfort indices (BROWN-BRANDL et al., 2005; BUFFINGTON et al., 1983; MITLÖHNER et al., 2001).

The lowest correlation for these indices was the RH, which are all negative with the lowest value for RTL (-0.645), followed by BGHI (-0.257) and TLI (-0.218). Along with the temperature and Ws (BERMAN, 2005), they can describe more precisely the effects of the environment on the animals ability to dissipate heat (BEATTY et al., 2006; WEST, 1999).

Table 4. Pearson correlation coefficient (r) between black globe temperature (Tg), air temperature (Ta), relative humidity (RH), wind speed (Ws), radiant thermal load (RTL), black globe-humidity index (BGHI), and thermal load index (TLI).

	Tg^{1}	Ta^{2}	RH^{3}	Ws^{4}	RTL^{5}	BGHI^{6}	TLI^{7}
Tg^{1}	1.000	0.764**	-0.489**	0.153*	0.809**	0.962**	0.956**
Ta^{2}		1.000	0.047ns	0.009ns	0.232**	0.899**	0.877**
RH^{3}			1.000	-0.028ns	-0.645**	-0.257**	-0.218*
Ws^{4}				1.000	0.366**	0.123ns	0.107ns
RTL^{5}					1.000	0.667**	0.677**
BGHI^{6}						1.000	0.992**
TLI^{7}							1.000

^{1}Black globe temperature,^{2}air temperature, ^{3} relative humidity, ^{4}wind speed, ^{5} radiant thermal load, ^{6}black globe-humidity temperature, ^{7}thermal load index. **p < 0.01, *p < 0.05, ns = non-significant.

Conclusion

The silvopastoral system provided better thermal comfort for the animals, by reducing the temperature of the globe and wind speed, and decreasing the BGHI, RTL and TLI, compared with the system without shade. Further studies are required about the formation of microclimate in silvopastoral systems and its effect on animal production.

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