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Dairy cows on integrated livestock-forestry system in the tropics

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Abstract Improvements in animal husbandry environment have resulted in major benefits to dairy farming in tropical regions. The aim was to evaluate the effect of changes in sun/shade regimes—restricted shade (RSR), moderate shading (MSR), and intense shading (ISR)—on the behavior of crossbred dairy cows. Massai grass with eucalyptus trees were used in the system. The experiment was conducted at Brazil from 2017 to 2018. Eight dairy cows were observed in each regime over three days by seasons every 30 min from 6 a.m. to 6 p.m. The behavioral variables considered were localization, posture, and activity. Microclimatic variables were studied and hourly averages were calculated for seasons. The experiment was conducted in randomized complete blocks with split-plots; evaluation times were allocated to subplots and sequential days of analysis were considered replications in time. Multivariate analysis (principal component analysis) was performed using Excel. The results showed that the RSR had a higher proportion of idle cows, which was associated with a higher intensity of radiation (1.2 MJ m^{-2} h^{-1}). The MSR and ISR differed in radiation levels by 17% and 58%, respectively. The opposite was true when shade was available, as cows performed activities such as grazing more frequently, mainly in the morning shift (difference of 20.7% in the RSR for the shade regime). The behavior of crossbred dairy cows subjected to climatic stress environments was benefitted from microclimatic conditions provided by trees. The provision at least moderate shade around the paddocks,

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alleviates the stress and regulates the vital activities of the animals.

Keywords Ambience · Grazing · Idleness · Photosynthetically active radiation · Shade

Introduction

The dairy sector is very prominent in the national and international agribusiness. Brazil, home to one of the largest herds of dairy cattle in the world (16.3 million cows milked year^{-1}), was ranked as the world's third largest milk producer in 2019 (FAOSTAT 2021), albeit with a low milk production per cow (average of 2206 L of milk cow^{-1} year^{-1}).

Moreover, the adverse effects of the thermal environment present in tropical and subtropical climate regions are among the factors that can limit milk production. Once high air temperatures prevail due to the high incidence of solar radiation and other climatic elements (humidity and wind) that may cause discomfort and affect the growth, production, milk quality, and reproduction of dairy cows (Biavatti et al. 2014; Lambertz et al. 2014; Vizzotto et al. 2015). Animals under thermal stress can change their behaviour to reduce the amount of endogenous heat produced and promote heat loss, resorting to reducing grazing time and increasing idle time and water consumption (Batista et al. 2019; Bear et al. 2012; Carnevalli et al. 2020). The reduction in grazing activity reduces food intake and, consequently, affects the productive performance of animals, resulting in milk production or reductions of body weight gain (Mellado et al. 2016).

In this regard, the Midwest region of Brazil (Mato Grosso) is known for having a maximum temperature ranging from 28 °C during the rainy season to 40 °C during the dry season, related to the lack of cloud cover in this period (Alvares et al. 2013). That fact increases the incidence of solar radiation, while relative humidity remains low owing to the lack of rain; these conditions can be considered inappropriate for dairy farming as they induce heat stress and compromise production and even animal survival (Vizzotto et al. 2015).

Agrosilvopastoral systems have great potential to overcome such adversities for example by improving thermal comfort by providing cattle with shade, thus an environment with a milder temperature, improving the nutritional value of forage, possibly providing animals with food supplements through grazing, or supplying preserved forage in the trough, resulting from the agricultural component production. Such measures have the potential to result in increases in milk production (Alves et al. 2017; Balbino et al. 2011; Rodrigues et al. 2019). Therefore, the objective of this study was to evaluate the behavioural changes of crossbred dairy cows subjected to sun and shade regimes in silvopastoral systems in a tropical climate region.

Methods

Location and animals

The experiment was conducted in the Experimental Field of Embrapa Agrosilvopastoral, Sinop city, Mato Grosso state, Brazil (latitude 11° 51′ 43″ S, longitude 55° 35′ 27″ W, and altitude of 384 m), in systems implemented since 2011. The experiment was conducted from 14 March 2018 to 18 March 2019. The soil in the area is classified as Orthic Ferralsol (FAO 2015). The municipality of Sinop is exactly in the transition between tropical monsoon climate (*Am*) and tropical savanna with dry winter (*Aw*) according to the Köppen-Geiger climate classification (Alvares et al. 2013; Souza et al. 2013). Precipitation data, relative air humidity (minimum and maximum), maximum temperature, and global solar radiation from the pre-experimental (21 December 2018 to 13 March 2019) and experimental periods (14 March 2018 to 18 March 2019) were obtained from the automatic meteorological station database (Embrapa Agrosilvopastoral 2022a, b), located in the experimental field (Fig. 1).

The experimental area was divided into three parts corresponding to different sun and shade regimes: Restricted shade regime with restricted access to shading (RSR occupying 2.4 ha); moderate shading regime (MSR occupying 2.6 ha); intense shading regime (ISR occupying 4.2 ha). The useful pasture area amounted to 2.4 ha in all treatments and included the area occupied by trees in the MSR and ISR. In the MSR, there were two double rows of trees located on the sides of the paddocks, with a spacing of 2 × 3 m and 52 m between rows (338 trees ha^{-1}; basal area of trees: 15.2 m^2 ha^{-1}).

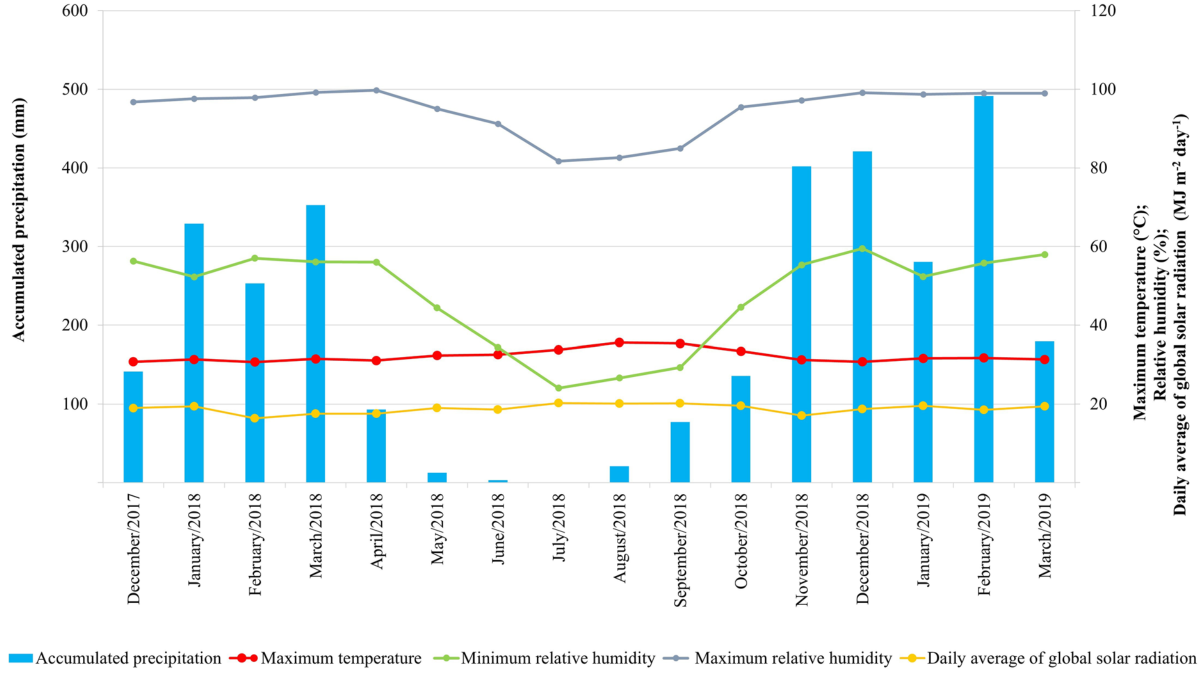

Fig. 1 Accumulated precipitation (mm), maximum and minimum relative humidity (%), maximum temperature (°C) and Daily average of global solar radiation (MJ m^{-2} day^{-1}) monthly of the experimental area. Source: Automatic meteorological station located in the experimental field of Embrapa Agrosilvopastoral in Sinop, state of Mato Grosso, Brazil

In the ISR, the trees (2 × 3 m) were arranged in triple rows 15 m apart (714 trees ha^{-1}; basal area of trees: 31 m^2 ha^{-1}). All tree lines were oriented towards the East/West (Fig. 2).

In RSR, the cows were allowed to access the shadings in the corridor during the warmest periods of the day. This was necessary to prevent collapse or death of the animals for their physiological responses to high temperature, low humidity and cloudiness in

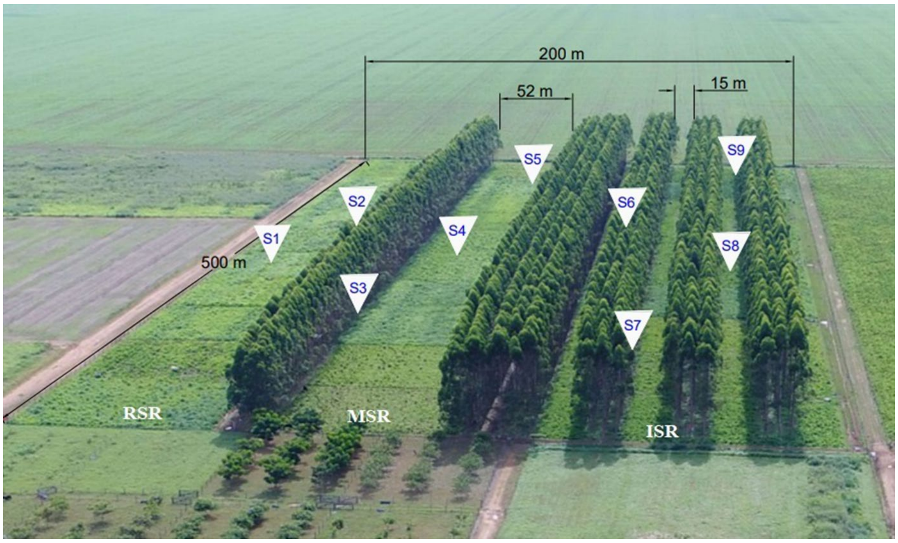

Fig. 2 Distribution of the nine meteorological station in the experimental area. Station 1 (S1): restricted shading regime (RSR); stations 2 (S2), S3, S4 and S5: moderate shading regime (MSR); stations 6 (S6), S7, S8 and S9: intense shading regime (ISR). Source: adapted from Gabriel Faria—Embrapa Agrosilvopastoral

the area, included dyspnoea, salivation, open mouth breathing with their tongue sticking out of the oral cavity and even nose bleeding.

The tree species used was the eucalyptus (*Eucalyptus urophylla* × *Eucalyptus grandis* clone H13), while the forage species was the Massai grass (*Megathyrsus maximus* cv. Massai), pastured on when their canopy intercepted 95% of light (pre-grazing) until it reached 50% of the starting height (post-grazing).

Six to eight crossbreds (3/4, 5/8, and 7/8 Black and White Holstein and Gyr), primiparous (at the beginning of the experiment), tester dairy cows were used in each treatment, with an average body weight of 588 kg (±46.2 kg), selected two months after delivery.

The cow groups were always kept adhering to an equivalent distribution of genetic grouping and lactation period in the different shade regimes. Replacements were carried out as needed. All animals had free access to water and a mineral mixture throughout the experimental period.

The behavioural assessments of the dairy cows were performed following a methodology adapted from Mello et al. (2017), by a single trained observer using binoculars, every 30 min, from 06:00 to 18:00 h. The following aspects were evaluated: location (sun or shade), posture (standing or lying down), and activity (grazing, visiting the silage trough, and being idle). Furthermore, animal behaviour evaluations were carried out in each season of the year, with three days of repetitions, typical and alternated and under the routine management of the experimental farm, to not influence the animals' natural behaviour during the day. The data obtained on the days those behavioural evaluations were undertaken, were grouped in the summer/2017 (14, 16, and 19 March 2018), autumn/2018 (13, 15, and 21 June 2018), winter/2018 (13, 17, and 19 September 2018), spring/2018 (10, 12, and 14 December 2018), and summer/2018 (13, 15, and 18 March 2019) stations.

The microclimatic variables [average air temperature (°C), relative humidity (%), photosynthetically active radiation (PAR; MJ m^{-2} day^{-1}) and wind speed (ms^{-1}) were collected from nine automatic meteorological station allocated as shown in Fig. 2 installed in the shade regime areas without repetition; therefore, the data were presented in a descriptive manner. Average soil temperature and global solar radiation data were obtained from an automatic meteorological station located in the restricted shade regime area and from another one located under the tree shade regime in the ISR area (next to the eucalyptus row), to obtain information on environments with and without the influence of shadow (extreme values).

For this purpose, specific sensors coupled to data loggers were used, programmed to read every five and obtain average and total values every 15 min, in addition to obtaining hourly and daily values.

The temperature and humidity index (THI) developed by Thom (1959), was adopted and proposed in this experiment as an attempt to characterize the thermal environment to replace the black globe temperature and humidity (ITGU) and radiant thermal load (CTR). It was not possible to measure the temperature of the black globe at the meteorological stations in the period for this experiment.

Data processing and statistical analyses

The statistical analysis of the data was performed using the PROC MIXED procedure of the SAS® On Demand software (SAS 2020) (Statistical Analysis System), under repeated measures over time, using the Akaike Information Criterion (Wolfinger 1993) to choose the variance and covariance matrices. Treatment means were estimated using "LSMEANS" and compared using the probability of difference (PDIFF) using Student's *t* test, at a 10% probability of error. Principal component analyses (PCA) were performed to identify homogeneous groups using XLSTAT® statistical package. For these analyses, only the variables that were significant by univariate ANOVAs were considered: location frequency (cows in shade), posture (standing), activity (grazing; being idle; visiting the silage trough), and microclimatic variables (mean and maximum temperatures, PAR, and THI). Kaisers' rule (Principal Components whose eigenvalues are equal or greater to one were retained—Kaiser 1960) was applied to select the principal components (PCs) used for visual inspection of the observations cloud in the plane of PCs, and to identify the correlating characteristics of the different treatments and seasons.

This research study was carried out with the authorization of the Animal Use Ethics Committee (CEUA) of Embrapa Agrosilvopastoral, under protocols 002/2016.

Results

Microclimatic characterisation

Small reductions in the average air temperature between 10:00 and 14:00 h were observed in all seasons of the year in shading regimes. There was a greater reduction in wind speed in the ISR owing to the increased tree density. The average THI values were higher than the critical THI of 72 (mean value of 73) throughout all seasons, even in shading regimes. The average relative air humidity peaked in the summer season of 2017 (85%), while it decreased to less than 50% in the winter (48%) and spring of 2018 (37%). However, this variable did not vary among the treatments (Table 1).

The PAR values ranged from 0.8 to 1.2 MJ m^{-2} h^{-1}, 0.6 to 1.0 MJ m^{-2} h^{-1}, and 0.4 to 0.7 MJ m^{-2} h^{-1} in the RSR, MSR, and ISR, respectively (Fig. 3).

The maximum PAR values were recorded at 13:00 h in the summer of 2017 in all regimes (Fig. 3). The maximum PAR value of the RSR was 17% and 58% lower than the values recorded for the MSR and ISR, respectively. During the autumn of 2018, the maximum PAR value in the MSR was recorded at

Table 1 Average air temperature in the interval between 10:00 and 14:00 h, average wind speed, temperature and humidity index, and average relative humidity on animal behaviour evaluation days during the different seasons in the restricted shade regime, moderate shading, and intense shading regimes

Treatments	Summer 2017	Autumn 2018	Winter 2018	Spring 2018	Summer 2018
Mean temperature between 10:00 *and* 14:00 h (°C)					
Restricted shade regime	26.7	29.6	33.7	28.2	31.3
Moderate shading regime	26.6	29.1	33.0	28.5	31.0
Intense shading regime	26.3	28.8	33.0	28.0	30.5
Wind speed (ms^{-1})					
Restricted shade regime	0.74	1.17	1.24	0.89	0.85
Moderate shading regime	0.75	1.16	1.24	0.77	0.82
Intense shading regime	0.66	0.88	1.0	0.73	0.75
Temperature and humidity index					
Restricted shade regime	76	74	80	77	78
Moderate shading regime	75	74	78	77	78
Intense shading regime	75	73	78	77	77

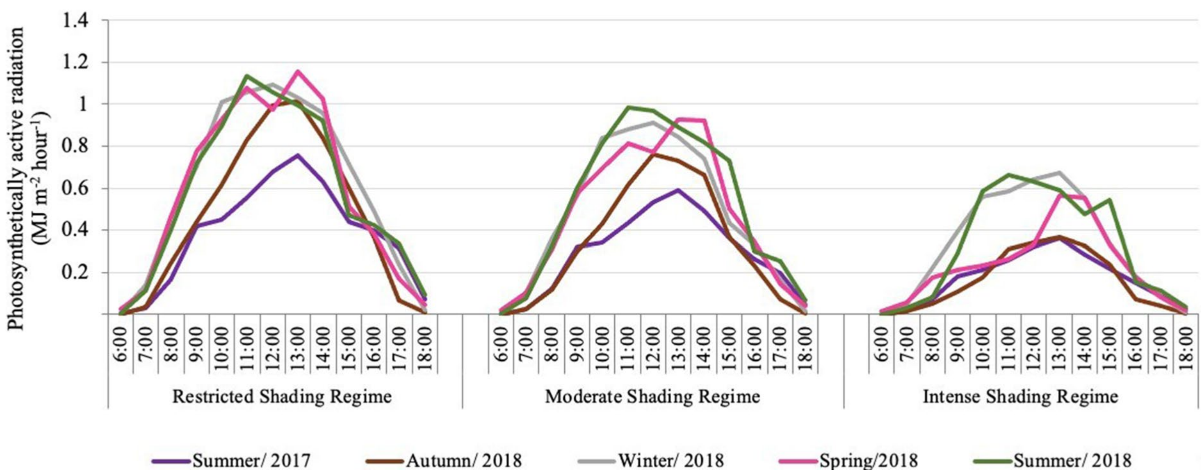

Fig. 3 Average flows of photosynthetically active radiation (MJ m^{-2} h^{-1}) in restricted shade regime, and under the canopies in moderate shading and intense shading regimes

12:00 h (0.8 MJ m^{-2} h^{-1}), while in the RSR and ISR, the maximum value occurred at 12:00 and 13:00 h, respectively (1.0 MJ m^{-2} h^{-1} and 0.4 MJ m^{-2} h^{-1}, respectively).

There were microclimatic differences (in soil temperature and global radiation, for example) between the restricted shade regime and shading environments. The maximum soil temperature value was recorded from 10:00 to 14:00 h during the winter of 2018 (31 °C at restricted shade regime), with a 10.3% difference from the intense shading regime. The lowest soil temperature among all seasons occurred in the autumn of 2018 (25 °C in the RSR and 23 °C in the shading regime), with a difference of 7.8% between the environments. The maximum global solar radiation value recorded occurred under the restricted shade regime of the winter of 2018 (on average 3.9 MJ m^{-2} day^{-1}), with a difference of 23% from the value recorded in the shading regimes. In the autumn of 2018, the greatest difference in global solar radiation was recorded between the RSR and the ISR (61%; average of 3.7 MJ m^{-2} day^{-1} and 1.4 MJ m^{-2} day^{-1}, respectively).

Summer/2017 and autumn/2018

During the period from the summer of 2017 to the autumn of 2018, which was marked by milking twice a day, the eigenvalues were higher than 1 in three principal components, accounting for 85.94% of the variability among observations. Principal component 1 (PC1) enabled a better differentiation of variables related to shading regimes and presented higher values for average air temperature, frequency of idle cows, temperature in the 10:00–14:00 h time interval, and PAR in the RSR, and lower values of these variables in the ISR (Fig. 4A). The values of the variables were similar in the MSR, and intermediate compared to those recorded in the other two regimes (Fig. 4A). Principal component 2 (PC2) showed a more conspicuous difference between the summer of 2017 and the autumn of 2018, with higher values of average grazing frequency and standing animals and of THI and lower wind speed values; these values were more highly associated with the summer of 2017 than with the autumn of 2018 (Fig. 4B).

Principal component 3 (PC3) showed a lower frequency of individuals in the shade in the RSR than in the MSR and ISR and grouped both shading regimes as similar (Fig. 4C).

There was a negative correlation between the frequency of cows in the shade and the frequency of idle cows (− 0.5062) and a positive correlation between the frequency of idle cows and PAR (+ 0.6704) and average air temperature (+ 0.4946) in the Pearson correlation matrix. The frequency of standing cows had a highly positive correlation with the frequency of grazing cows (+ 0.7564) and a negative correlation with wind speed (− 0.5973). There was a negative correlation between the frequency of grazing cows and wind speed (− 0.5874) and a positive correlation between THI and the average air temperature (+ 0.7160) as well as between the THI and PAR (+ 0.5831).

Winter/2018

During the winter of 2018, a period marked by one milking per day and supplementation of animal feeding with corn silage, the eigenvalues were higher than 1 in the three principal components, explaining up to 88.74% of the variability among observations. PC1 was more associated with the shading regimes, with the highest frequency of standing cows, average air temperature, average air temperature in the 10:00–14:00 h time interval, wind speed, and THI as well as the lowest frequency of cows in the shade, in the RSR compared with the ISR. It appears that the MSR response pattern was intermediate in relation to the RSR and ISR ones (Fig. 5A). An inspection of the PC1 and PC3 planes did not indicate differences between the shading regimes, which were associated with factors not evaluated in this study (Fig. 5B).

The correlation matrix showed that the frequency of cows in the shade had highly negative correlations with the frequency of standing cows (− 0.8947) and with PAR (− 0.8367). There was a highly positive correlation between the frequency of standing cows and PAR (+ 0.7407) and THI (+ 0.7039). There was also a highly positive correlation between the average air temperature and the average temperature in the 10:00–14:00 h time interval and with THI (+ 0.9105 and + 0.9268, respectively).

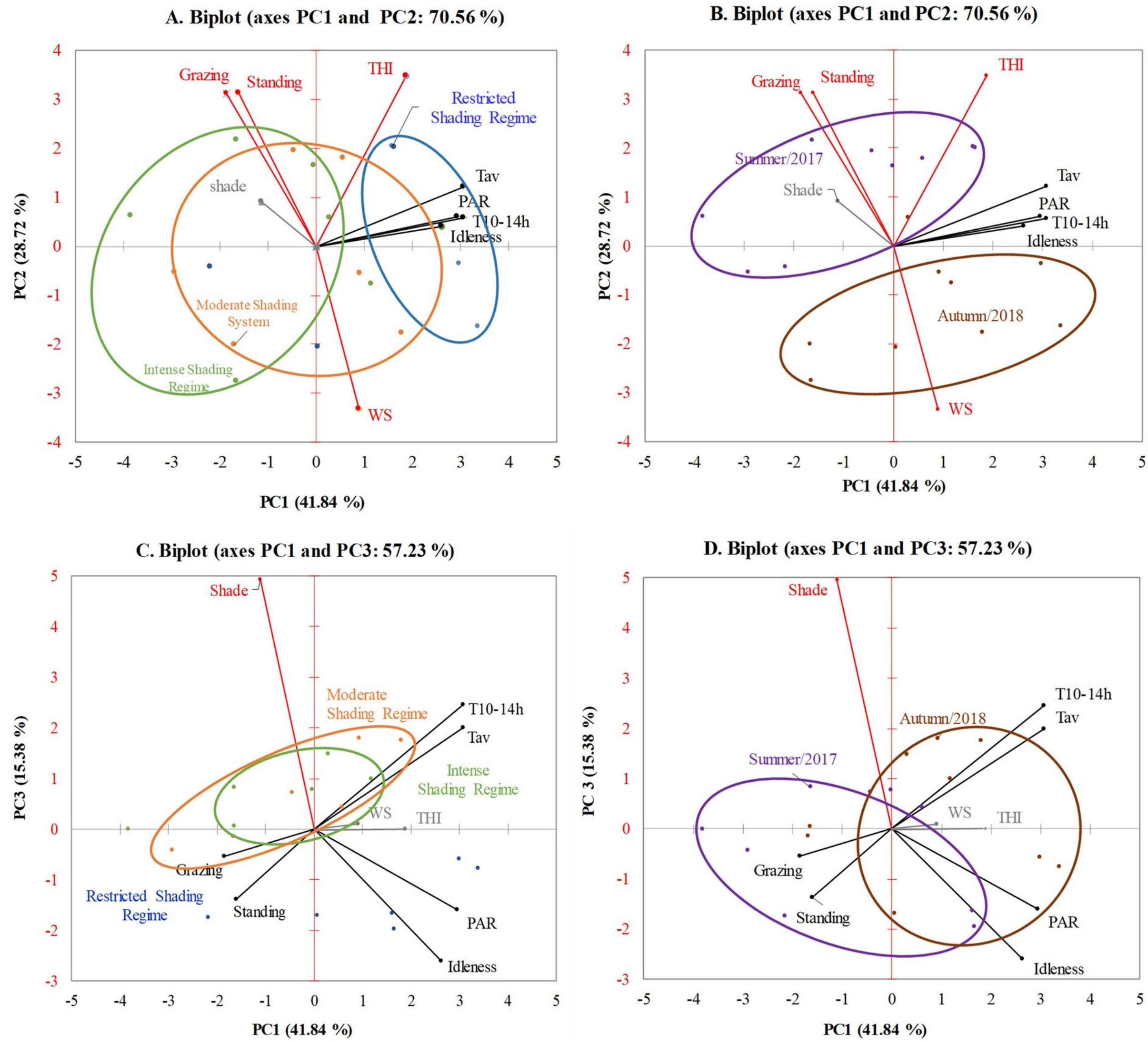

Fig. 4 Biplot representation of the principal component analysis (PCA) showing the correlation circle and the observations cloud in the plane of the principal components' pairs (PC1 × PC2 and PC1 × PC3). Legend: 4A and 4C: restricted shading regime (blue), moderate shading regime (orange), and intense shading regime (green). 4B and 4D: Summer/2017 (purple) and Autumn/2018 (brown). Average temperature (Tav); Average temperature between 10:00 and 14:00 h (T10-14 h); photosynthetically active radiation (PAR); temperature and humidity index (THI); wind speed (WS). (Color figure online)

Spring/2018 and summer/2018

In the period between the spring and summer of 2018, marked by the return to pasture and one milking a day, two principal components (PC1 and PC2) presented eigenvalues above one and accounted for up to 69.6% of the observed variability. The variables associated with PC1 and PC2 allowed for a better discrimination between seasons and the shading regimes, respectively (Fig. 6A, B). Higher temperatures between 10:00 and 14:00 h, mean air temperature, THI, and frequency of idle cows and lower frequencies of grazing cows were recorded in the summer of 2018 than in the spring of 2018 (Fig. 6B).

An analysis of PC2 indicated a contrast between the RSR and the shading regimes. However, it was

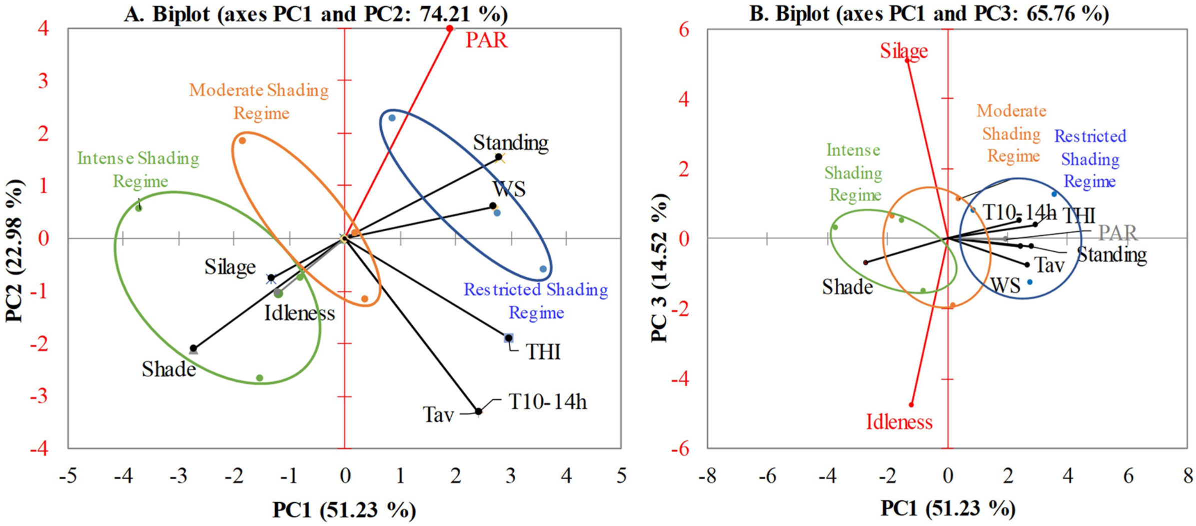

Fig. 5 Biplot representation of the principal component analysis (PCA) showing the correlation circle and the observations cloud in the plane of the principal components' pairs (PC1 × PC2 and PC1 × PC3). Legend: 5A and 5B: restricted shading regime (blue), moderate shading regime (orange), and intense shading regime (green). Average temperature (Tav); average temperature between 10:00 and 14:00 h (T10-14 h); photosynthetically active radiation (PAR); temperature and humidity index (THI); wind speed (WS). (Color figure online)

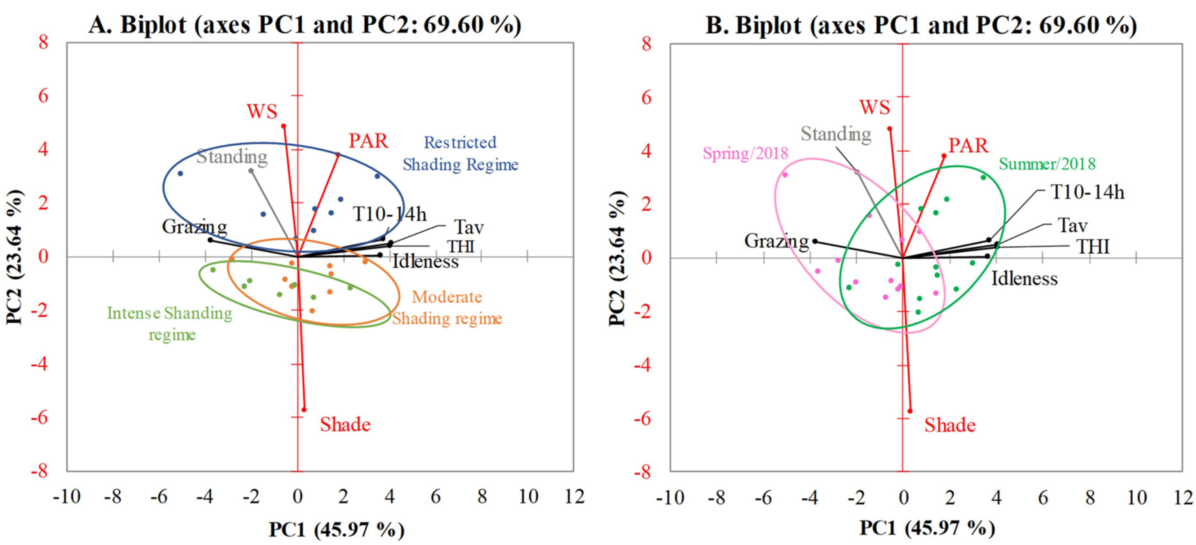

Fig. 6 Biplot representation of the principal component analysis (PCA) showing the correlation circle and the observations cloud in the plane of the principal components' pairs (PC1 × PC2). Legend: 6A: restricted shading regime (blue), moderate shading regime (orange), and intense shading regime (green). 6B: Spring/2018 (pink) and Summer/2018 (green). Average temperature (Tav); average temperature between 10:00 and 14:00 h (T10-14 h); photosynthetically active radiation (PAR); temperature and humidity index (THI); wind speed (WS). (Color figure online)

not possible to distinguish MSR from ISR. In the RSR, there were higher values for wind speed and PAR and lower values for the frequency of shaded cows compared to both shading regimes (Fig. 6A).

The Pearson correlation matrix showed a high positive correlation between average air temperature and THI (+0.9879) and a positive correlation between THI and the frequency of idle cows (+0.6085). A negative correlation was recorded between the frequency of grazing cows and THI (−0.6500), idleness (−0.7433), and the average air temperatures in the 10:00–14:00 h time interval (−0.6628 and −0.5985, respectively). The frequency of shadow searching was negatively correlated with the frequency of standing cows (−0.6071), PAR (−0.4109), and wind speed (−0.6023).

Discussion

The RSR affected the thermal comfort index such that the higher the THI. The greater the thermal discomfort, which was confirmed by the higher frequency of standing and idle cows seeking to reduce caloric increase and avoid metabolic heat generation that arises from performing other activities, such as grazing, rumination, and displacement (Mendes et al. 2013; Polsky and Von Keyserlingk 2017). Given the above, the MSR provided lower PAR incidence, temperature, and wind speed between rows, possibly balancing these microclimatic factors, reducing the THI, and alleviating the thermal discomfort of the animals when compared with the RSR environment.

Cows reduce grazing during hours when thermal comfort indices are unfavourable (high relative temperature and humidity), as feeding is an activity that produces heat (Carnevalli et al. 2020). Moreover, they can reverse their natural activity hours during the day, focusing on grazing in times that allow maximum thermal comfort. As verified by Geron et al. (2014), cattle avoid grazing during the hottest periods and increase grazing at night for 06:30 h in environments with high temperature.

The uncomfortable environmental conditions in the morning led to higher incidences of grazing activity in the afternoon and, as weather, conditions became milder, the animals gradually returned to grazing. Furthermore, the consumption of concentrate after milking in the morning led to satiety and encouraged the cows to seek shade upon returning to the paddocks, which may also have contributed to the increased grazing activity observed in the afternoon.

In this context, as cows under the RSR could not choose shade, they remained idle near the drinking fountain, trying to cool off by forming mud, to dissipate heat by conduction. These results corroborate those by Mello et al. (2017). The authors demonstrated, in the same experimental area, that increased temperature (35 °C to 36 °C) and relative humidity (87%) resulted in 61% of heifers choosing to cluster near the drinking fountain, in a muddy site, lying down and with mouths agape as a measure to alleviate thermal discomfort, returning to grazing only after 16:00 h. Some authors (Carnevalli et al. 2020, Deniz et al. 2020 and Giro et al. 2019) also showed the potential of the silvopastoral system to alleviate the high heat load of the animals, inducing the cattle to stay longer in these shaded areas.

The average wind speed observed in the RSR was higher than that in the ISR during spring, showing that the rows of trees acted as physical barriers (windbreakers) in the shaded regime. In turn, this yielded a negative correlation between this variable and the frequency of cows in the shade. Moderate wind can alleviate the animals' thermal stress in environments with worse thermal comfort conditions (high temperature, RAH, and THI), as it facilitates heat exchange by convection (Batista et al. 2019; Tavares et al. 2016).

Factors other than climate that may have altered animal behaviour patterns, e.g., the number of milking a day and the transition from pasture-only to pasture with silage feeding. Thus, in the autumn of 2018, the lower frequency of cows grazing occurred due to the transition in the volume of forage feeding, as forage production began to decrease due to its seasonality. Thus, grazing was less frequent, while visits to the silage trough became more frequent. The higher wind speed recorded in the autumn of 2018, was associated with a lower frequency of standing animals, and may have alleviated the thermal discomfort by increasing heat loss through sweating (Baêta and Souza 2012).

The greater cloud cover observed in the summer of 2018 and the minimum access to shade in the RSR alleviated the thermal discomfort and allowed the animals to carry out grazing activities during the hottest hours of the day.

The difference in average air temperature found among treatments was smaller than the expected and often observed in the field and was due to the type of sensor used in the meteorological station. Evidence indicates this type of sensor was not a good option for this kind of evaluation, since in were weather shelters. The soil temperature and global solar radiation values support this idea. Different sensors detected variations between the restricted shade regime and shading environments of 0.7 °C and 3.2 °C (2.8–10.3%) in soil temperature and 1.0 MJ m^{-2} day^{-1} and 2.7 MJ m^{-2} day^{-1} (23–61%) in global radiation, for the same time of the same day of assessment. Mello et al. (2017) used mini-station sensors and were able to detect differences of up to 7 °C in the same environment. Moreover, Pezzopane et al. (2011) observed maximum temperature differences greater than 1 °C between distant points in a grevillea (*Grevillea robusta*) shaded coffee production system. This indicates that sheltered sensors used in a total-station context should be avoided in this type of study.

On the days of animal behaviour evaluation (13, 17, and 19 September 2018), referring to the winter of 2018, the climatic conditions were atypical due to the transition from winter to spring, mainly characterised by the occurrence of isolated precipitation events in a short period of time. Despite isolated, such precipitation events (accumulated small precipitation; Fig. 1) may have alleviated the thermal discomfort in the RSR environment, even during the hottest hours of the day, and allowed cows to visit the silage trough from 14:30 to 17:30 h, highlighting the higher frequency (79.2%) observed at 14:30 h (Fig. 5).

Thus, the winter of 2018 was characterised by having a water deficit with less than 100 mm accumulated precipitation, along with the highest maximum temperature of 35 °C (Fig. 1). Based on these data, it appears that the environmental conditions were the most severe and adverse among the evaluated stations, mainly in terms of the thermal comfort of the animals. Cattle specialised in milk production have a thermoneutral zone between 4 and 26 °C (Perissinotto et al. 2009). Therefore, the temperature in this season (35 °C) exceeded the critical temperature of the animals.

Adverse microclimatic conditions stimulated the cows' idleness, a behaviour that helps reduce the caloric increase and prevent metabolic heat generation when performing activities such as grazing, rumination, and displacement (Mendes et al. 2013). The cows in the shading treatments preferred to remain idle in the shade, while those in the RSR remained idle near the trough, to dissipate heat by conduction, as they were unable to opt for shade.

In all the seasons of the year, silvopastoral systems changed the microclimate mainly by reducing radiation, and only the regime with the highest density of trees (ISR) reduced the wind speed. However, the lower incidence of radiation made the grazing activity more efficient (in seasons with forage supply) and made cows search for the silage trough (in the winter/2018 season) under this regime, thereby alleviating the severe and adverse climate conditions.

Conclusion

In conclusion, this study indicates the behaviour of crossbred cows is strongly altered by the microclimatic conditions provided by the presence of trees in pastures under severe environmental conditions that are unfavourable to thermal comfort in the tropics. The main changes are in the distribution of grazing and leisure activities throughout the day due to high temperatures and sunlight incidence. The provision of shade, even if moderate around the paddocks, reduces physiological stress and regulates the animals' vital activities, such as grazing, rumination, and idleness.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by ABSM, CABC, RAC, DAM, IB and JL. The first draft of the manuscript was written by ABSM and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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