SPATIOTEMPORAL THERMAL DISTRIBUTION IN AGROFORESTRY SYSTEMS IN THE TROPICS

Nivaldo Karvatte JUNIOR [1]; Roberto Giolo de ALMEIDA [2]; Caroline Carvalho de OLIVEIRA [1]; Flávio de Aguiar COELHO [3]; Fabiana Villa ALVES [4]

[1] Zootechnist. Pos-doctoral student. Department of Agricultural Science/Instituto Federal Goiano; [2] Agricultural engineer. Researcher. Embrapa Beef Cattle; [3] Zootechnist. Masters student. Department of Animal Science/Federal University of Mato Grosso do Sul; [4] Zootechnist. Researcher. Ministry of Agriculture, Livestock and Food Supply

ABSTRACT
The objective was to verify the spatiotemporal distribution on infrared temperature inside agroforestry systems. The study was carried out between June 2015 and February 2016, during the months corresponding to the winter and summer seasons, respectively, in Brazil. The experimental area of Embrapa Beef Cattle is located in Campo Grande (Mato Grosso do Sul), coordinates 20º24'53” S, 54º42'26” W and 558 m altitude, and is composed of two agroforestry systems with different densities and arrangements trees, totaling 12 ha. Pasture temperatures were determined using an infrared thermography camera and the records interpolated by the natural neighbor method. Results show spatiotemporal variations in infrared temperature, and the system with the lowest shade availability has the greatest heat accumulation area. This means that the environment inside agroforestry systems is not homogeneously comfortable for cattle.
Key words: Animal welfare; geostatistics; microclimate

INTRODUCTION

In agroforestry systems, the combination of trees in different densities and spatial arrangements affects the thermal environment with a variety of processes and feedbacks, highly dynamic and correlated in space and time. By intercepting direct solar radiation, trees reduce heat load below the forest canopy, providing cooler environmental through evapotranspiration and shading (OLIVEIRA et al., 2017; KARVATTE JR. et al., 2020). In this sense, considering an animal as a thermodynamic system that continuously exchange energy with the environment, studies evaluating heat load in grazing systems are important to assess thermal environment available for farming animals (MAGALHÃES et al., 2020).

Indicators such as surface temperature of pasture are highly variable, requiring observations in both high spatial and temporal resolution. These temperature variations result from physical and biological interactions affected by leaf morphology and albedo, tree canopy position, radiation, wind and stomatal response to the environment, directly influenced by season and regional climate (GERSONY et al., 2016; KIM et al., 2016). In this sense, infrared thermography can be used to describe in detail the patterns of leaf thermal variations and their relationship with environmental variables that characterize microclimate in agroforestry systems, extending traditional measurements to a spatial and temporal scale because, regardless of the application, all collected data are influenced by atmospheric conditions.

Our hypothesis is that different shade availability can result in spatiotemporal variations in infrared temperature in agroforestry systems. Therefore, the goal of this study was to verify the spatiotemporal distribution of infrared temperature inside agroforestry systems.

MATERIAL AND METHODS

A trial was conducted at the experimental farm of the Brazilian Agricultural Research Corporation (Embrapa Beef Cattle), located in Campo Grande, State of Mato Grosso do Sul, Brazil (20º24′53″ S, 54º42′26″ W, average elevation: 558 m), between June 2015 and February 2016, covering a dry winter and a rainy summer season, respectively. Local climatic pattern is in the transition between warm temperate (Cfa) and humid tropical (Aw), with precipitation and average annual temperature of 1.560 mm and 23,0ºC respectively (KÖPPEN, 1948).

The experimental area, with 12 ha, is composed of two agroforestry systems (AS-1 and AS-2), both divided into four paddocks of 1.5 ha, established in 2008 with piatã grass (*Urochloa brizantha* cv. BRS Piatã). In the AS-1 system, the forest component used is eucalyptus (*Eucalyptus grandis* x *E. urophylla*, clone H 13; average height of 26 m during the experimental period), planted in simple line rows (22 m and 2 m; density of 227 trees ha^{-1}), with a displacement of −20.41°S and − 54.71°W, in relation to the East-West axis. The AS-2 system has native trees from the Brazilian Cerrado (*Dipteryx alata* Vogel and *Gochnatia polymorpha* Less), which have been preserved and have an approximate density of 3 trees ha^{-1}.

The evaluations were carried out during four consecutive days in each experimental month, simultaneously evaluating one paddock of each system per day. The data were recorded from 08:00 am to 04:00 pm (GMT -04:00, at hourly intervals). Infrared images of all systems were captured using a professional thermographic camera (Testo®, model 875 2i), according Karvatte Jr. et al. (2020). Subsequently, images were analyzed using the IRSoft® software (Testo), obtaining values of pasture temperatures ($T_{Pasture}$), at equidistant points in the shade projection (2.0 m, 4.0 m and 6.0 m) and in full sun (2.0 m, 4.0 m and 6.0 m), in relation to the lines of trees. $T_{Pasture}$ values (°C) were also obtained at equidistant points between tree rows (0 m, 3.6 m, 7.3 m, 11.0 m, 14.6 m, 18.2 m and 22.0 m), identifying the location of the trees in AS-2.

The thermographic records were interpolated by the natural neighbor method, using the free software QGIS (version 3.10) and presented in the form of spatiotemporal thermal distribution maps identified between the rows of trees and differentiation between full sun and shade.

RESULTS AND DISCUSSIONS

Spatiotemporal thermal distribution maps show higher infrared temperatures (IT) during summer, in both agroforestry systems (Figure 1). Despite the greater thermal area observed in the AS-1 system (IT ≤ 32 °C), greater IT were identified in the AS-2 system (IT ≤ 35 °C). The daytime variation (8 a.m. to 4 p.m.) shows minimum temperatures recorded at 8 a.m. (IT ≥ 25 °C) and maximum temperatures between 11 a.m. and 2 p.m. (IT ≤ 35 °C).

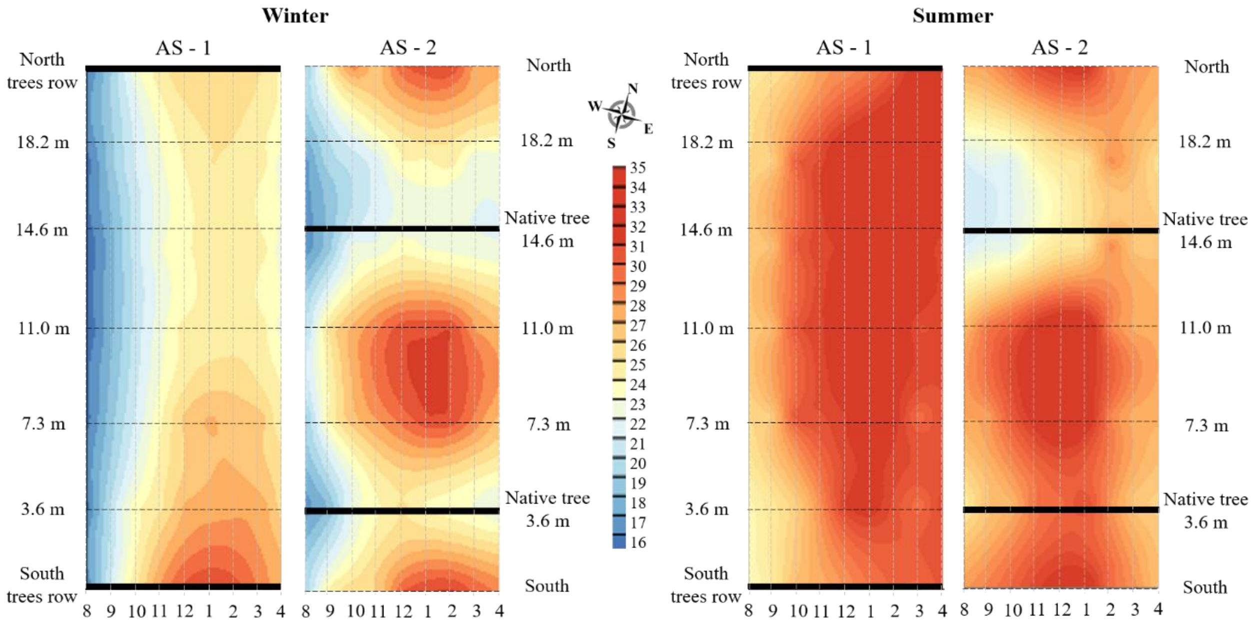

Figure 1. Spatiotemporal distribution of infrared temperature between rows of trees in agroforestry systems with eucalyptus (AS-1) and native trees (AS-2), during the winter and summer seasons.

Interactions found confirm the hypothesis of this study and show the differences in IT that represent the interface responsible for the spatiotemporal patterns of dissipation of daytime and seasonal pulses of solar energy that reach Earth's surface. In both systems assessed, during summer $T_{Pasture}$ was from 1.2 to 1.8 °C higher than the temperatures obtained in winter, possibly due to increase in solar radiation during the summer, which can reach up to 1000 W m^{-2}, according to Silva (2006). In fact, in this study, we observed that during winter, shade was projected in Southwest direction in the morning, characterizing a greater distribution of shade among tree rows in AS-1 system and wide individual shade projection in AS-2 system. In contrast, during summer, shade remained under canopy or a few meters from trees, projected Northwest in the morning in both systems. These results represent the effect of solar declination throughout the year and apparent solar movement further and corroborating with other similar studies (PEZZOPANE et al., 2017; MAGALHÃES et al., 2020).

Spatiotemporal thermal distribution for assessment sites reveals greater IT recorded in full sun (average variation of 26.5 ± 4.6 °C in winter and 31.2 ± 2.3 °C in summer, for AS-1 and 27.7 ± 5.3 °C in winter and 30.8 ± 3.3 °C in the summer, for AS-2) (Figure 2). However, the AS-2 system showed consistently higher temperatures throughout the experimental period and in both evaluated locals (average variation of 24.9 ± 8.1 °C for winter and 29.6 ± 4.5 °C for summer). Previous studies suggest that introduction of trees in pastures, in adequate density, acts as protection against thermal radiation load, since they reduce heat load associated with solar radiation (Karvatte Jr et al., 2016; Oliveira et al., 2017). In fact, our results show that in both seasons, forest canopy was effective in preventing extremes of thermal heating in the shaded environment (average IT reduction of 4.2 ± 2.0 °C in winter and 3.6 ± 1.0 °C in summer of AS-1 system and 5.5 ± 3.5 °C in winter and 2.3 ± 1.4 °C in summer, of AS-2 system).

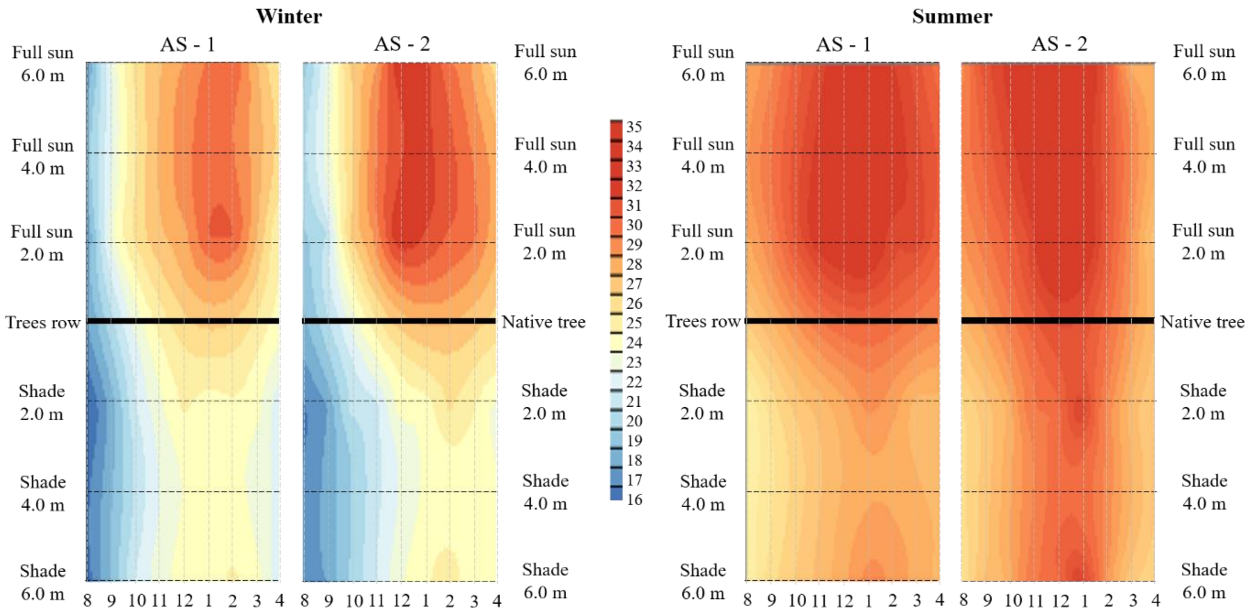

Figure 2. Spatiotemporal distribution of infrared temperature in full sun and shade in agroforestry systems with eucalyptus (AS-1) and native trees (AS-2), during the winter and summer seasons.

CONCLUSIONS

Spatiotemporal thermal distribution has shown that the environment inside agroforestry systems is not homogeneously comfortable but depends on the displacement and projection of shadow due to the spatial orientation of the tree rows.

ACKNOWLEDGMENTS

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Goiás (Fapeg) and Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul (Fundect), for the financial resources granted. To Embrapa Beef Cattle and Federal University of Goiás, for the experimental area and technical-scientific support.

REFERENCES

GERSONY, J. T.; PRAGER, C. M.; BOELMAN, N. T.; EITEL, J. U. H.; GOUGH, L.; GREAVES, H. E.; GRIFFIN, K. L.; MAGNEY, T. S.; SWEET, S. K.; VIERLING, L. A.; NAEEM, S. Scaling thermal properties from the leaf to the canopy in the Alaskan Arctic tundra. **Arctic, Antarctic, and Alpine Research**, v. 48, n. 4, p. 739–754, 2016. Available at: http://www.bioone.org/doi/10.1657/AAAR0016-013.

KARVATTE JR., N.; KLOSOWSKI, E. S.; ALMEIDA, R. G.; MESQUITA, E. E.; OLIVEIRA, C. C.; ALVES, F. V. Shading effect on microclimate and thermal comfort indexes in integrated crop-livestock-forest systems in the Brazilian Midwest. **International Journal of Biometeorology**, v. 60, p. 1–9, 2016.

KARVATTE JR, N.; MIYAGI, E. S.; OLIVEIRA, C. C.; BARRETO, C. D.; MASTELARO, A. P.; BUNGENSTAB, D. J.; ALVES, F. V. Infrared thermography for microclimate assessment in agroforestry systems. **Science of The Total Environment**, v. 731, n. 139252, 2020.

KIM, Y.; STILL, C. J.; HANSON, C. V.; KWON, H.; GREER, B. T.; LAW, B. E. Canopy skin temperature variations in relation to climate, soil temperature and carbon flux at a ponderosa pine forest in central Oregon. **Agricultural and Forest Meteorology**, 226–227, 161–173, 2016.

KÖPPEN, W. **Climatologia**: con um estúdio de lós climas de la tierra. México: Fondo de Cultura Econômica, 1948. 479p.

MAGALHAES, C. A. S.; ZOLIN, C. A.; LULU, J.; LOPES, L. B.; FURTINI, I. V.; VENDRUSCULO, L. G.; ZAIATZ, A. P. S. R.; PEDREIRA, B. C.; PEZZOPANE, J. R. M. Improvement of thermal comfort indices in agroforestry systems in the southern Brazilian Amazon. **Journal of Thermal Biology**, v.91, n.102636, 2020. Available at: <https://doi.org/10.1016/j.jtherbio.2020.102636>.

OLIVEIRA, C. C.; ALVES, F. V.; ALMEIDA, R. G.; GAMARRA, E. L.; VILLELA, S. D. J.; MARTINS, P. G. M. D. A. Thermal comfort indices assessed in integrated production systems in the Brazilian savannah. **Agroforestry Systems**, v. 92, p. 1659 - 1672, 2017.

PEZZOPANE, J. R. M.; BERNARDI, A. C. C.; BOSI, C.; OLIVEIRA, P. P. A.; MARCONATO, M. H.; PEDROSO, A. F.; ESTEVES, S. N. Forage productivity and nutritive value during pasture renovation in integrated systems. **Agroforestry Systems**, v. 93, p. 39–49, 2017.

SILVA, R. G. Predição da configuração de sombra de árvores em pastagens para bovinos. **Engenharia Agricola**, v. 26, p. 268–281, 2016.